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DEVELOPMENT OF WATER RESOURCES OF APPALACHIA. VOLUME 18. APPEND--ETC(U)
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Development
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in
APPALACHIA

ORIGINAL CONTAINS COLOR PLATE
REPRODUCTIONS WILL BE IN BLACK AND WHITE



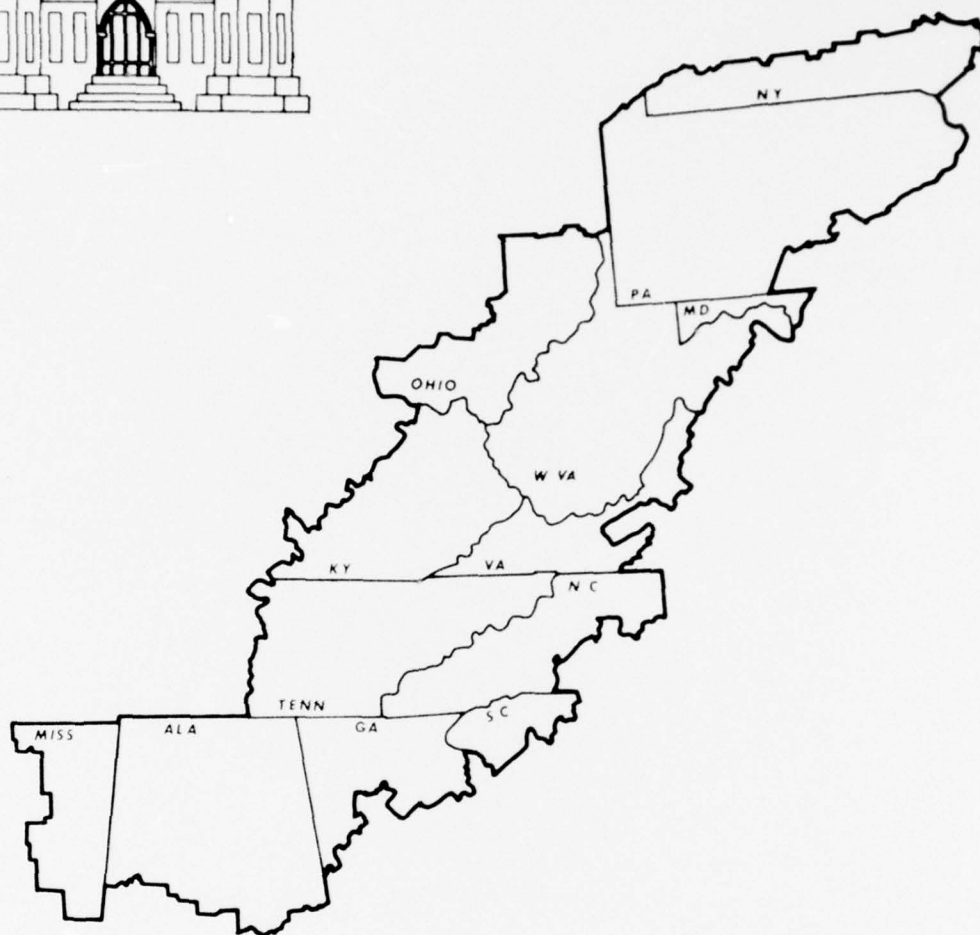
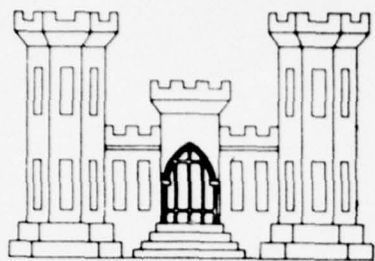
APPENDIX C
THE INCIDENCE & FORMATION
OF MINE DRAINAGE POLLUTION

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AND
U. S. DEPARTMENT OF INTERIOR





DEPARTMENT OF THE ARMY
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TO: THE READER

This document
Appendix C, "The Incidence and Formation of Mine Drainage Pollution" is one of nine appendices to the "Report for Development of Water Resources in Appalachia." It furnishes information on mine drainage pollution of Appalachian streams.

Effluent from coal mining activities is the major source of water pollution in most of the Appalachian coal basin. The pollution problems result from mineral acidity created when pyritic material, exposed during mining, is oxidized and the products are dissolved and carried into streams and lakes. Erosion and resultant sedimentation of the streams and lakes is another pressing problem connected with mining. Other factors contributing to reduced water quality during and after mining, i.e., hardness and mineralization, are problems, but they do not appear to be as important as acidity and sediments.

Acidity in mine drainage effluent corrosively attacks all steel and concrete structures which it contacts. Included are all water craft and fixtures built in and along streams and lakes, as well as those facilities utilized to withdraw water for municipal and industrial purposes. Additional treatment costs may also be incurred by the water users. Acid mine drainage reduces the pH level of the affected waters. Low pH has an adverse impact upon aquatic life, reducing or eliminating the quantity and quality of fish, thereby having a serious detrimental influence upon an area's recreation potential.

Appendix C and its five attachments discuss the chemical complexity of the formation of acid mine drainage, identify its extent and intensity, and analyze various corrective measures that may be taken to correct or better control the problem. This Appendix C is also Appendix C to the Appalachian Regional Commission's report entitled "Acid Mine Drainage in Appalachia" (June 1969). As a result of the evidence developed in the Commission's report, no massive effort to completely prevent acidity in Appalachia's streams is being proposed because of the expense and uncertainty of the abatement techniques and the relatively small amount of measurable damages.

Water resource developments for all uses are summarized in the main report which should be consulted for an overall view of the Appalachian region. An index for the report components and appendices is shown on pages v and vi of this appendix.

John C. H. Lee, Jr.
JOHN C. H. LEE, JR.
Colonel, Corps of Engineers
Director

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REPORT FOR DEVELOPMENT

OF

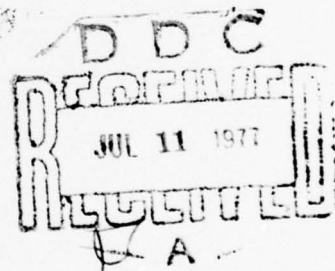
WATER RESOURCES OF APPALACHIA,

Volume 18.

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of
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June 1969

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APPENDIX C

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THE INCIDENCE AND FORMATION OF MINE DRAINAGE POLLUTION

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REPORT
For
DEVELOPMENT OF WATER
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APPENDIX C - THE INCIDENCE AND FORMATION OF MINE DRAINAGE POLLUTION

SECTION I - INTRODUCTION

1. AUTHORITY

This appendix is included in two different reports. Appendix C is Volume 18 of the U.S. Army Corps of Engineers, Office of Appalachian Studies' report entitled Development of Water Resources in Appalachia, a water resources survey prepared under authority of the Appalachian Regional Development Act of 1965, Public Law 89-4, approved March 9, 1965. Section 206 of the Act directed the Secretary of the Army, in cooperation with all appropriate State and Federal agencies, to prepare a plan for developing the water and related resources of the region, with special attention to measures needed for economic and social improvement. Section 206(b) recognized prevention of water pollution by drainage from mines as one of the measures which may be needed to meet the objectives of the plan.

Section 120(b) of Public Law 90-103, the Appalachian Amendments of 1967, directed the Appalachian Regional Commission to conduct a study detailing the impact of mine drainage pollution upon the economic development of Appalachia. This appendix, bearing the same title, is also Appendix C to the Appalachian Regional Commission's (ARC) report entitled Acid Mine Drainage in Appalachia (1969).

2. CONNECTION BETWEEN APPALACHIAN REGIONAL COMMISSION AND OFFICE OF APPALACHIAN STUDIES REPORTS

The original intent of Appendix C, as part of the water resources survey, was to determine the economic impact of mine drainage pollution on Appalachia, investigate the state-of-the-art of mine drainage abatement techniques, and suggest appropriate remedial and preventive measures and programs. However, because this modest effort largely duplicated the more thorough and recent work of ARC and its consultants, it was decided, in conjunction with ARC and other appropriate agencies, to restrict the main body of Appendix C to a brief description of the extent and intensity of mine drainage pollution in Appalachia and a more detailed discussion of the chemistry of the formation of acid mine drainage.

Additionally, five attachments are an integral part of the appendix. Attachment A is an atlas of the incidence of mine drainage pollution in Appalachia's streams compiled by the Federal Water Pollution Control Administration. The atlas was completed in 1967, but it has been updated to more accurately reflect the current situation. Attachments B through E were compiled by the Bureau of Mines of the Department of Interior during 1967-68. Attachment B is an annotated bibliography of the important literature extant at the time of publication. Although slightly dated, the attachment remains an excellent source of information. Attachments

C and D briefly analyze the factors contributing to the formation of mine drainage pollution. Attachment E surveys the costs of controlling acid mine drainage using various abatement techniques.

At the inception of the Commission's studies, the attachments were made available to ARC and its consultants as well as to other interested agencies. Part of the material contained in the various attachments was utilized by the Commission and its consultants and, therefore, appears either in the main body of ARC's report or in an appendix to said report. As an example, Appendix B (Engineering Economic Study of Mine Drainage Control Techniques) to the ARC report utilized and greatly expands upon some of the methods for controlling mine drainage discussed in Attachment E. However, each Attachment to this Appendix is sufficiently unique to make valuable contributions to the literature.

In addition to the detailed research concerning the feasibility and cost of various techniques for controlling mine drainage pollution, the Commission and its consultants investigated the impact of mine drainage pollution on industrial water users in Appalachia (Battelle Memorial Institute, Appendix A), upon the location decisions of manufacturing firms (The Fantus Company, Appendix D), upon recreation activities (Robert R. Nathan Associates, Inc., Appendix E), and the biological and ecological effects (Dr. Max Katz, Appendix F). An additional study, Appendix G (A Program for Simulation of Acid Mine Drainage in a River Basin), accompanies the ARC report.

The findings indicated that approximately three percent (5,700 miles) of Appalachia's streams are polluted by acid mine drainage. The pollution mainly occurs in Pennsylvania, West Virginia, and Ohio. About 78 percent of the annual acid load comes from inactive mines.

The investigations indicate that the mine drainage pollution has little or no impact upon industrial location decisions, and it does not add significantly to the cost of most water users. When the pH level of water is less than 5.0, aquatic life is seriously inhibited, so sports fishing is eliminated in highly acid water.

Total estimated annual savings to water users resulting from a 90 percent reduction in mine drainage pollution are \$4.2 million. Current estimates of the cost of a 95 percent abatement program for active and abandoned mines to be conducted over a 20-year period are \$6.6 billion. Therefore, major abatement programs would have to be justified on grounds other than traditional economic efficiency criteria.

The efficacy of most abatement techniques, especially at-source techniques, leave much to be desired. Water users can treat the water they withdraw from polluted sources less expensively than would be the case if they should assume their share of the cost of an at-source abatement program. They are also more certain of achieving water quality necessary for their particular use with direct treatment.

The Commission concludes, and the Office of Appalachian Studies concurs, that there is no justification for permitting present and future mining operations to allow pollutants to enter streams. State and Federal water quality laws are in the process of tightening the controls on various effluents, and it is expected that this process will continue. Preliminary information shows that some coal firms are able to abate acid effluents and to absorb the extra costs without reducing their competitive position in the energy markets; however, industry-wide surveys are not available to demonstrate changes that may be anticipated in the energy market were such abatement requirements, along with other environmental constraints, applied uniformly in all States.

Because of the many demands for funds to deal with a wide assortment of water related programs, no massive attack on pollution from abandoned mines is recommended. Present abatement techniques have not proven to be consistently successful, so it appears that there is no basis at present for huge expenditures. Continued research designed to improve the existing techniques should be funded.

3. SUMMARY STATEMENT OF MAIN BODY OF APPENDIX C

Section II identifies the geographical distribution of Appalachia's coal fields (Shown on Plate II) and discusses the history of coal mining in the area. The mine drainage pollution is generally coincidental with regions that have been or are presently being mined. The worst off- fending areas are in the old coal fields of West Virginia and Pennsylvania, and in a few areas of southeastern Ohio which have been stripped in recent decades.

The evidence concerning whether or not the annual volume of mine drainage pollutants has increased during the past few years is incon- clusive, but it appears that the annual acidity load has remained rather stable during the last two decades. However, the rapidly growing U.S. economy requires ever increasing amounts of energy and, at least for the next few decades, coal will provide a large percentage of the needed fuel input. Appalachian states will provide most of the coal. Without effective preventive measures, the detrimental impact of mine drainage effluent on the region's water quality will be much greater in future years.

Section III discusses the geochemical reactions that produce the solutes in mine drainage. A variety of mineral and other chemically active substances, such as carbon dioxide, become dissolved in all subsurface drainage waters. The particular reason for concern with regard to mine drainage is the presence of certain constituents, partic- ularly sulfates, in unusually high concentrations, and their rapid entry into streams while still reactive. Most chemical equations illustrate the production of acidity in mine drainage, but they do not accurately reflect the composition of mine drainage. The impression given is that only iron compounds and sulfuric acid occur in mine drainage to cause the

pollutional effects. This is not accurate since many minerals other than pyrite are also involved. The indication that the acid remains in mine drainage is particularly misleading. The initial oxidation of pyrite produces sulfuric acid, but not more than trace amounts of the sulfuric acid persist in mine drainage within the mine because the acid is so highly reactive. Mine drainage can more accurately be considered as a solution of mixed salts, predominately sulfates, usually containing silica and sometimes highly charged with dissolved carbon dioxide. Hydrolysis of the dissolved materials in mine drainage in streams will later again form acid, causing a drop in the stream's pH level.

The section further discusses the problems associated with water quality measurements and interpretations when dealing with waters containing mine drainage pollutants. The influence of seasons upon the quantity and impact of acid mine drainage is analyzed. The conclusions suggest opportunities for reasonable variations in timing the application of abatement techniques to reduce the costs during an annual cycle.

Section IV suggests a selective attack upon inactive mine drainage pollution sources. In a valley where a flood control project will make recreational, industrial, and residential growth possible, the project should not be forgone because of mine drainage pollution. The planner should evaluate the benefits and costs of the proposed project with and without a mine drainage abatement program. A mine drainage pollution control program should be included in the project package whenever the potential benefits are seriously inhibited without abatement. An example is the Corps of Engineers' proposed St. Petersburg Reservoir on the Clarion River in western Pennsylvania. Good water quality and flood control will bring many benefits to the Clarion, Allegheny, and upper Ohio River basins. To realize the potential benefits of the project an effective mine drainage program must be included.

SECTION II - EXISTING EXTENT AND INTENSITY POLLUTION

4. COAL DISTRIBUTION, PRODUCTION, AND EXTENT POLLUTION

Anthracite Coal Distribution - Relative to bituminous coal beds, the anthracite fields and anthracite coal beds are located in northeastern near the northern end of the valley and ridge II).*/

Bituminous Coal Distribution - The Appalachian basin is 800 miles long, extending from northwestern Alabama. It attains its greatest width in Pennsylvania and Ohio, and is only 35 miles wide at its southern point in Tennessee. Except for a small area in the Appalachian coal basin is entirely within the Appalachian Plateau. The area underlain by bituminous coal coincides with the Appalachian Plateau physiographic province.

Figure II-1 represents an entire geologic section in the coal basin. Thickness of all the individual coal seams, varies throughout Appalachian location, one or more of these strata may be encountered. In addition to variation in thickness, a typical coal seam may contain partings or lenses of shaly material which must be processed.

*/ U.S. Geological Survey and the Bureau of Mines, Resources of the Appalachian Region, U.S. Government Printing Office, Washington, D.C., 1968, pp. 104-107.

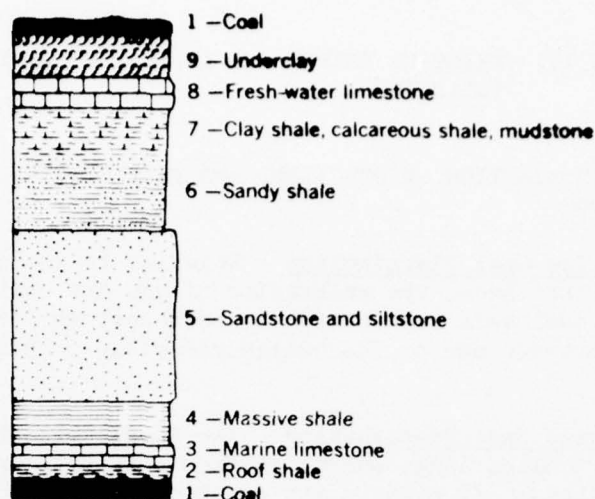


Figure II-1 Idealized Sequence of Beds in Cyclothem of Ohio Coal Region.

SOURCE: R. A. Brant and R. M. DeLong, "Coal Resources of Ohio," Ohio Division Geological Survey Bulletin, No. 58, 1960, p. 23.

Appalachian Coal Production - Twenty-three billion tons of bituminous coal had been taken from the Appalachian coal basin from the beginning of production through 1964, providing 62% of the total cumulative coal production of the United States. Bituminous coal production reached its peak of 468,609,000 tons in 1947 and, except for the Korean War and Suez Crisis, output declined until the early sixties (Figure II-2, Table II-1). In 1964, Appalachian bituminous coal production was 351 million tons, and the anthracite fields produced an additional 17 million tons. Coal production has increased steadily since the recession of the early sixties (Figure II-2).

Currently, approximately three quarters of the total United States coal production comes from the Appalachian Region. Mining occurs wherever coal is economically accessible, but varies considerably over the coal belt. Nine of the thirteen Appalachian states produce coal, West Virginia leading with a production of more than 141 million tons in 1964. The four counties of Logan, McDowell, Mingo, and Wyoming in southwestern West Virginia produced nearly 11 percent of the nation's coal. Pennsylvania ranked second, producing 76.5 million tons of bituminous coal. At the other extreme, Georgia's coal area is quite limited, and output is relatively small (Table II-1).

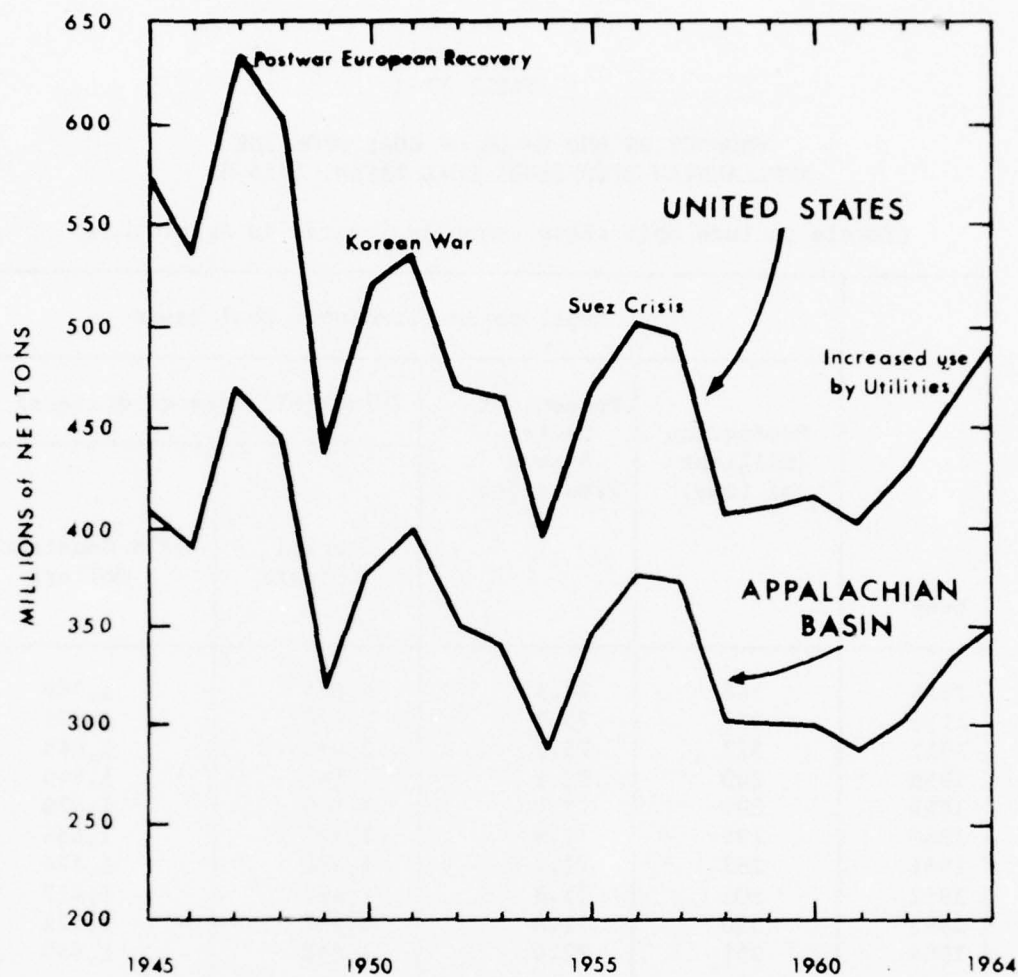


Figure II-2 Coal production in the Appalachian bituminous coal basin and United States, 1945-1964.

SOURCE: U.S. Geological Survey and the U.S. Bureau of Mines, Mineral Resources of the Appalachian Region, U.S. Government Printing Office, Washington, D.C., 1968, pp. 105, 108.

TABLE II-1

PRODUCTION AND VALUE OF COAL FROM THE
APPALACHIAN BITUMINOUS COAL BASIN, 1955-64

(Totals include only those counties located in Appalachia)

Year	Appalachian Bituminous Coal Basin			
	Production (millions of tons)	Percent of United States Production	Value (millions of dollars)	
			Current Dollars	1958 Constant Dollars
1955	346	74.5	1,645	1,789
1956	377	75.2	1,928	2,031
1957	373	75.7	2,012	2,045
1958	300	73.1	1,546	1,546
1959	299	72.4	1,500	1,479
1960	290	71.9	1,377	1,464
1961	287	71.2	1,382	1,374
1962	301	71.4	1,427	1,417
1963	330	71.8	1,527	1,521
1964	351	72.0	1,648	1,640

Source: U.S. Geological Survey and the U.S. Bureau of Mines,
Mineral Resources of the Appalachian Region, U.S.
Government Printing Office, Washington, D.C., 1968.
p. 108.

Extent of Mine Drainage Pollution - Mine drainage causes appreciably reduced water quality in the Appalachian States of Pennsylvania, West Virginia, Ohio, Kentucky, Tennessee, Virginia, Alabama, and Maryland. In Virginia, Tennessee, Maryland, and Alabama mine drainage pollution is mostly limited to small, often remote areas. Mining is widespread in southeastern Ohio and eastern Kentucky; hence, mine drainage problems are more extensive. However, significant water quality reduction due to acidity is restricted in most cases to tributaries rather than the main stem of streams draining these two states. Pennsylvania and West Virginia are heavily dependent on mining over wide areas; stream pollution associated with mining activities is significant throughout both states, degrading water quality in portions of most of the major river systems (See Plates I and II, pages C-43 and C-45).

5. INTENSITY OF MINE DRAINAGE POLLUTION

All of the Appalachian States report water quality problems, but only two states, Pennsylvania and West Virginia, consider pollution from mine drainage to be their highest priority water problem.*/ Most of the states, including other coal producing states, consider such water problems as pollution from industrial plants, municipal sewage, feedlots, thermal discharges, and erosion, as well as water storage for municipal supply and low flow augmentation, to be more important than mine drainage pollution control.

The intensity of coal mining provides a generalized concept of areas in the Appalachian Region where mine drainage pollution problems may arise, but the local geology, mining conditions, and changes which occur after mining more directly determine the specific types of pollution produced. The intensity of mine drainage pollution also may be related to the length of time the coal fields in the area have been open, and to the total amount of coal that has been removed from those particular fields. However, in most cases, the ultimate effect of time is to diminish mine drainage pollution.

The Monongahela River system is affected by mining activities more than any other river system in Appalachia, and contributes importantly to West Virginia's and Pennsylvania's reported acidity loads. West Virginia's water pollution problems caused by mine drainage are concentrated in two areas - the northern portion around the Monongahela River where acidity problems predominate, and in the southwestern

*/ Pennsylvania State Planning Board, Pennsylvania State Water Resources Supplement to the U.S. Army Corps of Engineers, "Report for Development of Water Resources in Appalachia," Harrisburg, Pa., Jan. 1968, p. 36.

Edgar H. Henry, "Water and Related Resource Development in West Virginia," Water Development Coordinating Committee for Appalachia, Minutes, 7th Meeting of Coordinating Committee, November 15-16, 1967, p. 5.

counties drained by the Guyandotte and Coal River systems where sediment causes the major problems.

Pennsylvania has the most widespread mine drainage pollution problems, including the central and southwestern portions of the state as well as the anthracite region in the northeastern portion. Pennsylvania estimates that a total of 2,750 tons of acidity enters the state's streams daily (1,003,750 tons annually).*/ Pennsylvania's streams contain approximately 46 percent of the 6,000 tons of mineral acidity reportedly entering Appalachia's waters daily.

The limestone in Ohio and Kentucky provides neutralization of much of the acidity produced before it reaches major streams. Both states have relied heavily upon strip mining, but, relative to Ohio, Kentucky's pollution problems are more closely associated with sedimentation than with acidity (See Plates I and II). The topography is rugged in eastern Kentucky and the soils are highly erodable, particularly when the vegetative cover is disturbed.

6. IDENTIFIED WATER QUALITY PROBLEMS ASSOCIATED WITH COAL MINING

Eight of the nine coal producing states in the Appalachian Region have identified water quality problems associated with coal mining. Georgia has limited mining activity, and no mineral acidity has been reported in that state's streams. A brief discussion of the location and intensity of mine drainage pollution in each of the other states follows:

Alabama - Some mine drainage pollution exists in the Black Warrior River Basin near Tuscaloosa. U.S. Geological Survey categorizes the affected streams as generally containing free mineral acidity, while the Federal Water Pollution Control Administration lists the streams as intermittently acidic.**/

*/ Pennsylvania State Planning Board, op. cit., pp. 36-49.

**/ For a detailed discussion of acid mine drainage pollution on a basin-by-basin basis see: Federal Water Pollution Control Administration, Stream Pollution By Coal Mine Drainage In Appalachia, which is Attachment A to this Appendix, 1967 (revised 1969), and William J. Schneider, et. al., Water Resources of the Appalachian Region, Pennsylvania to Alabama, U.S. Geological Survey, Hydrologic Atlas - 198, 1965, Sheet 9. Material compiled from these publications is presented in Plates I and II of this Appendix.

Kentucky - There is limited mine drainage pollution on the upper reaches of the Cumberland River in Harlan, Bell, and Knox Counties. Minor pollution also exists in Laurel, Whitley, and McCreary Counties on Cumberland River tributaries. The upper reaches of the Kentucky River, especially the North Fork and its tributaries have reduced water quality, but continuous pollution from mine drainage exists only in a few minor tributaries in the vicinity of Hazard and Whitesburg. Intermittent free mineral acidity appears in the Levisa Fork of the Big Sandy River. Sedimentation is a bigger problem than acidity in eastern Kentucky streams.

Maryland - Streams in the vicinity of the Savage River Reservoir southwest of Cumberland, Maryland, and in the north branch of the Potomac River have limited mineral acidity.

Ohio - Many streams in eastern Ohio are continuously or intermittently acidic. The Muskingum and Hocking River Basins have extensive stretches containing continuously acidic water. Acidity is most intense in Raccoon Creek, which drains directly into the Ohio River.

Pennsylvania - Pennsylvania has reported 2,300 miles of streams polluted by coal mine drainage. The problem is extensive throughout the bituminous coal basin in the west-central part of the state and the old anthracite region surrounding Wilkes-Barre, Hazelton and Pottsville (See Plate I).*/ The Monongahela, Conemaugh, Kiskiminetas, Clarion, Loyalhanna, Susquehanna, Lackawanna, and Schuylkill River systems are acidic.

Tennessee - Mine drainage presents a minor problem along tributaries throughout the coal bearing region traversed by the Tennessee River. The East Fork of the Obey River is continuously acidic and creeks in northern Tennessee in the vicinity of Jellico are also acidic.

Virginia - Limited amounts of mine drainage pollution exist along tributaries of the Clinch and Powell Rivers in the southwest corner of the state.

West Virginia - Pennsylvania is the only state that surpasses West Virginia in miles of streams polluted and tons of acidity produced each year. The Monongahela River Basin is polluted throughout its length, much of which lies in the northern part of West Virginia. The southwestern portion of the state has large quantities of mine drainage pollutants, most of which are associated with sedimentation rather than acidity.

*/ Pennsylvania State Planning Board, op. cit., p. 49.

Remaining Appalachian States - The remaining Appalachian States, Mississippi, New York, North Carolina, and South Carolina, have no coal mines, and none of these states has reported any water quality deterioration from coal mine effluents.

7. HISTORICAL TRENDS IN ACID MINE DRAINAGE PRODUCTION

More than 50 years of standard water quality records of the U.S. Geological Survey and Public Health Service are available for some of the major Appalachian streams, but few attempts have been made to analyze the data in detail to determine whether there are trends in acid production. Variations in seasonal and annual rainfall, mining intensity, and other factors make trends and relationships difficult to ascertain.

Over a long time-span, discernible trends in acidity have taken place in the Youghiogheny and Monongahela Rivers at their confluence, as demonstrated by Clark.^{*/} The trends were made evident by using six-year moving averages of mean annual acidity to reduce year-to-year variations. Acidity in the Youghiogheny River was at its peak concentration during the 1920's, but declined over the next 25 years to about one-fifth of the earlier level, then held fairly constant into the 1960's. Trends in acidity of the Monongahela River were different, increasing toward higher concentrations until the mid-1930's, then decreasing somewhat toward lower values. The long-term trends in acidity observed by Clark are illustrated in Figure II-3. According to his findings, no marked changes in acidity levels have occurred in recent years.

Declining trends in acidity were not attributed to mine sealing or to changes in mine operation procedures, but partial credit was given to industrial neutralization of acid water.^{**/} Levels in acidity were observed to reflect a closer relationship with annual than with cumulative coal production.^{***/} Upstream reservoirs began operation during the period investigated and were shown to reduce acidity in the rivers, particularly during low flow augmentation in the critical summer and fall seasons.

Detailed analyses of this kind are not available for other streams in the Appalachian Region, but other general reviews have been made.

^{*/} C. Scott Clark, "Some Factors Involved in the Oxidation of Coal Mine Pyrite and Water Quality Trends in the Monongahela River Basin," Coal Industry Advisory Committee, Symposium on Acid Mine Drainage Research, Mellon Institute, Pittsburgh, Pa., May 20-21, 1965, pp. 35-50.

^{**/} Ibid., p. 41.

^{***/} Ibid., p. 48.

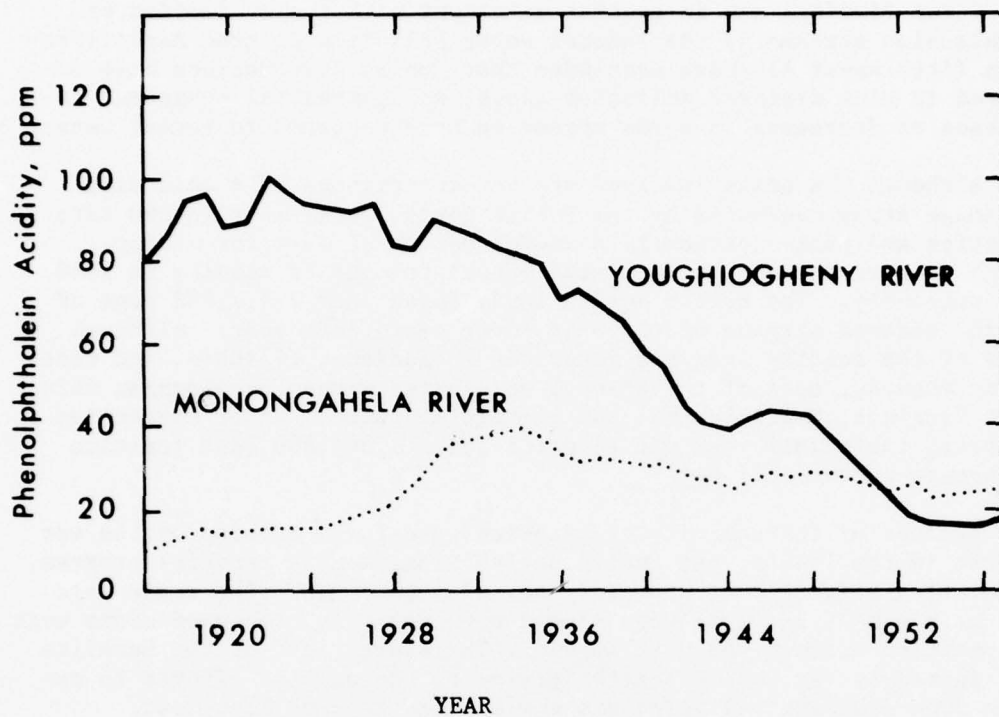


Figure II-3 Six -year moving averages of the yearly average values of phenolphthalein acidity for the Monongahela and Youghiogheny Rivers.

SOURCE: C. Scott Clark, op. cit., p. 39.

Tybout*/ recently concluded from USGS time-series records that there has been no trend toward either increased or decreased acidity since 1940 in the Monongahela River at Charleroi, Pennsylvania. For other rivers, the 1940 acidity observations were compared with those of recent years, and no overall trends were indicated.

These findings are in general agreement with the evaluation of Appalachian streams by the Federal Water Pollution Control Administration (Attachment A) which concludes that "while fluctuations have occurred in mine drainage pollution loads, no substantial permanent increases or decreases in loads appear to have occurred in recent years."**/

Although the areas involved are not coterminous, the acid mine drainage study conducted by the Public Health Department in the late thirties and early forties is a useful source of data for making rough comparisons of the estimated annual tonnage of acidity in 1940 and presently. The Public Health study found that 2,477,983 tons of "acid" entered streams of the Ohio River Basin each year. Although some of the acidity load was generated in Indiana, Illinois, and western Kentucky, most of the tonnage originated within Appalachian Ohio, West Virginia, Pennsylvania, and eastern Kentucky. After corrective efforts, the annual load was reported to be 1,864,800 tons (calcium carbonate equivalent).***/

Because of the scarcity of resources and funds created by the war effort in the 1940's, the Public Health Department's remedial program, consisting primarily of mine sealing, was abandoned. The seals were not maintained, and some were broken when formerly abandoned mines were reopened to augment the coal supply. Therefore, most of the benefits attributed by the Public Health Service to the earlier efforts to reduce mine drainage pollution are now assumed to have been lost.

As a result of the 1956 Water Pollution Control Act (PL 84-660) and more recent amendments, national interest in mine drainage pollution control has been revived. The Federal Water Pollution Control Administration now estimates that 6,000 tons of acidity are discharged

*/ Richard A. Tybout, "An Economic Framework for Evaluation of Acid Mine Drainage," Proceedings, Second Annual Symposium on Water Resources Research, Water Quality and Recreation in Ohio, June 15-16, 1966, Ohio State University, Ohio, p. 229.

**/ FWPCA, op. cit., p. 257.

***/ Ohio River Committee, Ohio River Pollution Control, 78th Congress, 1st Session, House Document No. 266, August 27, 1943, U.S. Government Printing Office, Washington, D.C., Supplement C, p. 23.

daily into Appalachia's streams.*/ This output is equivalent to about 2.2 million tons per year, and includes pollution in the Susquehanna, Delaware, and Potomac River Basins, some in Tennessee and Alabama, as well as that in the portion of the Ohio River Basin within Appalachia. The currently estimated amount of acidity is not appreciably different from that reported in the 1943 Public Health Survey Report. In contrast to Clark's conclusions, the Public Health study predicted continued increase in mine drainage on the assumption that there is a proportional relationship between cumulative coal production and the annual volume of acidic mine drainage.**/

8. ACID PRODUCTION PROSPECTS FOR FUTURE

In discussing future prospects, Martin and Hill assumed a five percent yearly increase in acidic mine drainage.***/ Presumably the assumption is based upon an expected continuing increase in coal production at about five percent annually, which is approximately of the same magnitude as the 6.8 percentage annual increase in coal production noted during the early sixties.****/

While it is logical to assume that there was an early relationship between cumulative coal production and volume of acidic mine drainage, it appears unlikely that a straightforward, proportional relationship will continue in future years. The potential acidic pollution is dependent upon the amount of pyritic material associated with the coal relative to the naturally alkaline minerals in the same area. Pennsylvania's coal fields, which are deficient in alkaline minerals, supplied a large percentage of the coal produced during the first half of the nineteenth century.

A rapid increase in acid production may be associated with the opening of new coal fields. The northern coal fields, relatively deficient in alkaline minerals, are the oldest mining areas in the country. Coal output will continue to expand in the old fields, exposing additional acid producing minerals, but any development of major, new coal fields will probably be in the southern part of Appalachia where the natural alkalinity is relatively greater.

*/ FWPCA, Attachment A, p. 3.

**/ Ohio River Committee, op. cit., p. 23.

***/ Edward S. Martin and Ronald D. Hill, "Mine Drainage Research Program of the Federal Water Pollution Control Administration," Ohio River Valley Water Sanitation Commission, Second Symposium on Coal Mine Drainage Research, Pittsburgh, Pa., May 14-15, 1968, p. 53.

****/ U.S. Geological Survey and the U.S. Bureau of Mines, op. cit., p. 108.

The mining technique has an important impact upon the long run creation of mine drainage pollutants. Self-draining deep and auger mines are potential suppliers of acid for an indefinite period. Oxidation of new pyritic material which is exposed through slow collapsing of the mine roof and walls can continue for literally hundreds of years. Water flowing through the mine then transports the acidity into the streams. Deep mines that are not self draining and that can be permanently inundated once the mine has ceased operations will produce acid only during the period of active mining.

Strip mines may actually produce more acidity during early stages of coal production than deep mines, but the total acid production is more controllable. Stripping exposes large quantities of pyritic material initially, but proper reclamation again buries the pyrite, reestablishes drainage, and provides a vegetative cover to prevent erosion. Long term acid production is thereby prevented.

States have shown much greater initiative in passing legislation designed to diminish pollution from surface mining than has been the case with deep mines. Since World War II the percentage of coal tonnage coming from strip mines has steadily increased. Therefore, because nature and man can generally more rapidly correct surface disturbances and because surface mining operators are now legally bound to carry out a reclamation program, there is little likelihood of a proportional relationship between cumulative coal production and growing quantities of annual acid production.

SECTION III - THE SOURCE AND NATURE OF MINE DRAINAGE POLLUTION

9. WATER POLLUTION FROM MINES

Water pollution by drainage from mines occurs when dissolved, suspended or other solid mineral wastes and debris from mining or mine-related operations enter streams, watercourses, or ground water. Mine drainage includes not only water flowing by gravity or pumped from underground mines, but also runoff or seepage from surface mines and from excavated waste deposits. Additional pollution can result from washing and processing the extracted minerals. Both process water and mine drainage may contain similar pollutants and require similar treatment for preservation of stream utility and water quality.

10. COAL, THE MAJOR SOURCE OF MINE DRAINAGE POLLUTION

Water pollution from coal mine drainage in the Appalachian Region is a widespread problem because coal is widely distributed and iron disulfide minerals such as pyrite and marcasite are often associated with the strata in which coal is found. Oxidation of iron disulfide exposed by mining initiates the formation of soluble acidic pollutants which cause the most objectionable characteristics of coal mine drainage. A major share of the economic damages caused by mine drainage is attributable to acidity, and 93 to 97 percent of acidic mine water pollution has been associated with coal mining.*/

11. THE POLLUTANTS IN COAL MINE DRAINAGE

Both underground and surface mines contribute to the mineral wastes which comprise the pollutants in mine drainage. Surface mines and deep mine waste rock deposits contribute much of the solid sediments which enter Appalachian streams. Both surface and underground mines contribute to the load of dissolved pollutants. In broad geographic perspective, northern Appalachia is more seriously affected by the mine drainage pollution problems caused by dissolved constituents: toward the central and southern portions of the region, land erosion and stream sediment problems predominate.

Coal mine drainage contains the same substances in solution that are present in naturally alkaline ground waters, including dissolved carbon dioxide and calcium bicarbonate. In addition, mine drainage contains more

*/ U.S. Department of the Interior, Surface Mining and Our Environment, U.S. Government Printing Office, Washington, D.C., 1967, p. 63.

sulfates from the oxidized pyrite. The sulfate content of fresh mine drainage is balanced by an equivalent content of metallic ions (cations) in solution, indicating that the dissolved mineral constituents are salts and that no free sulfuric acid is present in more than trace amounts.*/

Different constituents in mine drainage cause different levels of stream and water quality impairment. Grouped in the approximate order of their detrimental effects, the constituents of particular concern in mine drainage are:

1. The sulfates of iron and aluminum in solution as a consequence of pyrite oxidation, seriously affecting chemical water quality.
2. The solid mineral debris and sediment in streams as a result of mudslides and hydraulic erosion, particularly affecting stream channels.
3. A broad group of other dissolved and colloidal products of geochemical origin which have less serious impact on streams.

A brief discussion of these groups follows.

The first category, iron and aluminum sulfates, has greater adverse effect on water quality and causes more economic damage to streams than any other dissolved constituents. These salts in solution cause the extremely low pH and high titratable acidity values sometimes encountered, and account for the corrosiveness and the aquatic life toxicity characteristic of some mine drainage. Ferrous sulfate is formed directly by pyrite oxidation, but it is relatively slow to react chemically until oxidized to the ferric state. On the other hand, the sulfuric acid produced by pyrite oxidation is highly concentrated and reactive, and almost immediately reacts with the rock minerals within the mines, forming aluminum sulfate as well as other soluble decomposition products with which it comes in contact. The term "sulfuric acid" is descriptive of the relatively intense acid and corrosive nature (pH 4.5 and below) of mine drainage containing ferric and aluminum sulfates.

The second category of constituents, solid mine wastes, causes extensive pollution and damage to Appalachian streams and watercourses.

*/ Silas A. Bralev, Commonwealth of Pennsylvania, Department of Health Industrial Fellowships, No. 1-7 inclusive, Mellon Institute of Industrial Research, Pittsburgh, Pa., Feb. 1954, pp. 272-3.

The solid sediments consist of a broad mixture of loose waste rock, earth, and mineral matter, including fragments of waste coal. Obvious surface gullying, landslides, and streambank caving of wastes offer some evidence of the problem at its source, and stream-bed debris can be seen in tributaries of major streams. Hydraulic erosion of loose mine wastes is particularly severe during thunderstorms. Suspended sediments may persist far downstream.

An indication of the magnitude of the waste deposition problem in major streams is the fact that several private firms currently make a profit dredging rivers for coal. Although the coal comprises only a minor fraction of the solid wastes entering streams, annual recovery by dredging during recent years has been around 700,000 tons of coal in the anthracite fields alone.*/ Dredging produced over 1.5 million tons in 1941 when anthracite was in greater demand.

Damages from deposition of solid wastes include the reduction of channel capacities, increased flooding, sedimentation of reservoirs, and adverse impact on aquatic life. Water quality is affected by the increase in suspended sediments and by the acidity from pyritic wastes deposited in streams.

The third group of constituents in mine drainage consists of a variety of minerals which have relatively less serious polluttional effects on the streams. Some of the substances, such as dissolved carbon dioxide and bicarbonates, occur in natural waters and have well known effects on water quality. Included among these are calcium and magnesium bicarbonates which produce the desirable alkalinity and undesirable carbonate hardness in waters, and ferrous bicarbonate which consumes oxygen and causes bitter taste, staining and other known effects, but not acidity.

Of more immediate concern are the constituents induced or aggravated by mining which enter streams in greater amounts because of mining, including the more stable dissolved sulfate salts and the colloidal iron and aluminum hydroxide precipitates. The dissolved sulfates primarily are salts of calcium, magnesium, and manganese. These salts do not affect aquatic life at concentrations found in Appalachian streams, but are not removed by ordinary water treatment for municipal supply, thus causing reduced water quality for domestic use by causing noncarbonate hardness and staining.

The colloidal sediments are produced when dissolved iron and aluminum are precipitated from solution as insoluble hydroxides. Since such water would already be of poor quality (low pH, corrosive, toxic to fish),

*/ U.S. Geological Survey and the Bureau of Mines, op. cit., pp. 104-107, 125.

the adverse effect of such chemical precipitation is limited chiefly to the unsightly appearance of streams. Formation of the colloidal precipitate releases hydrogen ions which are more reactive and readily neutralized, and indicates definite progress in improvement of water quality by removal of the iron and aluminum from solution. Colloids form as a result of aeration (in the case of iron) and increased alkalinity from admixing water or stream-bed minerals. Until such chemical precipitation is complete, the affected water remains unsuited for aquatic life or most other uses.

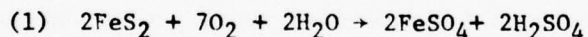
12. THE FORMATION AND REACTIONS OF SOLUBLE CONSTITUENTS IN MINE DRAINAGE*/

The geochemical reactions that produce the solutes in mine drainage are fairly well known to persons with technical knowledge. A variety of mineral and other chemically active substances (e.g., carbon dioxide and organic acids) become dissolved in all subsurface drainage waters. The particular reason for concern with regard to mine drainage is the presence of certain constituents, particularly sulfates, in unusually high concentrations, and their rapid entry into streams while still reactive.

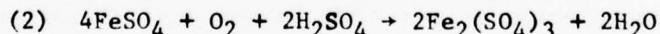
Several types of chemical equations can be used to illustrate the reactions which produce mine drainage constituents. Stoichiometric relations that include both cationic and anionic balance appear to represent reactions more completely and precisely than if ions are considered separately. Thus, ferrous iron may occur in either acidic or alkaline drainage from mines, but the difference is discernable only if the soluble iron is shown to occur as either ferrous sulfate or ferrous bicarbonate. Knowledge of the complete system and its behavior is essential to make judgments and decisions for efficient control and amelioration of mine drainage pollution.

The chemical reactions which produce the soluble substances that characterize acid mine drainage are generally portrayed in three stages:

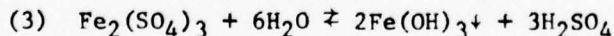
First, the moist atmospheric oxidation of the sulfide in exposed pyrite which produces ferrous sulfate and sulfuric acid:



Second, the oxidation of ferrous sulfate in solution by dissolved oxygen, producing ferric sulfate:



Third, the hydrolysis of ferric sulfate in water, producing colloidal ferric hydroxide and sulfuric acid:



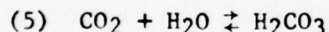
*/ See also Attachments C and D to this Appendix C.

These equations are useful for illustrating the production of acidity in mine drainage, but are not meant to reflect accurately the composition of mine drainage. The impression given is that only iron compounds and sulfuric acid occur in mine drainage to cause the pollutional effects. This is not an accurate depiction since minerals other than pyrite are also involved. The indication that the acid remains in mine drainage is particularly misleading. While it is true that the initial oxidation of pyrite produces sulfuric acid, not more than a trace of the original sulfuric acid persists in mine drainage, as the acid is so highly reactive. Rather than an acid solution, mine drainage can more accurately be considered as a solution of mixed salts, predominately sulfate, usually containing silica and sometimes highly charged with dissolved carbon dioxide. Of course, acid is later formed as the drainage hydrolyzes in the streams.

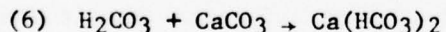
Reaction of the sulfuric acid with calcareous rock or other basic minerals at the site of pyrite oxidation results in the formation of neutral sulfate salts. With sufficient limestone, dolomite, calcite and similar basic minerals in the mine environment, the neutral salts formed are predominately sulfates of calcium and magnesium. Calcium sulfate (gypsum) has limited solubility and may remain incompletely dissolved until there is a period of excess moisture. Magnesium sulfate, on the other hand, is highly soluble and dissolves readily on contact with only limited amounts of water. Sulfuric acid neutralization by calcareous shale or limestone is illustrated by the following chemical equation:



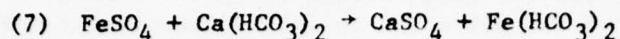
The carbon dioxide thus produced plays an additional important role in the formation of alkalinity in mine water. Alkalinity is desirable for reducing the potential acidity due to ferrous sulfate in the mine drainage. The solubility and retention of carbon dioxide is dependent on water depth and volume in the mine, as well as the lack of opportunity for aeration. When carbon dioxide remains dissolved in the mine water, a carbonic acid solution is formed:



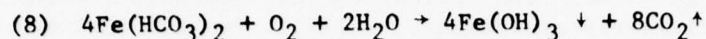
The carbonic acid, in turn, reacts with additional calcite or limestone, bringing calcium bicarbonate into solution and producing alkalinity in the mine drainage water. The reaction proceeds as follows:



When mine drainage of this nature reaches the surface and is aerated, it does not become acidic even though it still carries its original content of ferrous sulfate. In effect, only the calcium and sulfate ions are stable and remain in solution as a neutral salt, while the iron and bicarbonate ions become unstable on exposure to the atmosphere, and the iron is precipitated. This complex reaction can be more readily visualized if considered as occurring in two stages: first, the formation of the stable calcium sulfate in solution, thus:



and second, the elimination of the unstable iron bicarbonate from solution as a result of aeration:



Iron is thus eliminated by oxidation and precipitation as ferric hydroxide, and bicarbonate is dissipated by the evolution and loss of carbon dioxide from the drainage solution into the air.

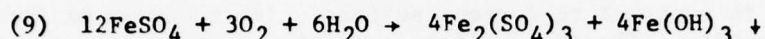
The volume, depth and fluctuation of water in the mine plays a critical role in the balance of acidity and alkalinity in effluent mine drainage. In the Appalachian region, liquid water is not necessary for the initial oxidation of pyritic materials due to the availability of sufficient moisture in the mine air. The rate of pyritic oxidation in liquid water is dependent on the quantity of dissolved oxygen and its rate of diffusion through water. Oxidation is actually faster in air than in water. Liquid water acts primarily as the vehicle for dissolving and transporting the solutes in mine drainage. Only minimal amounts of water are necessary for transporting the iron and aluminum sulfates causing acidity, since those salts are extremely soluble and high concentrations can be readily carried; more than 12 percent total dissolved solids has been observed in mine drainage. Fluctuations in water depth promote the solution of salts formed on the mine walls.

The alkalinity of mine drainage, however, is directly dependent on water volume and depth in a mine. These factors determine the amount of carbon dioxide retained in solution, and so determine the amount of calcium bicarbonate alkalinity brought into solution through the action of carbonic acid on calcite in the mine rock. Shallow flowing water retains little carbon dioxide and picks up little alkalinity in the mine, while water in deep pools has more opportunity to increase in alkalinity through reaction with basic minerals in the mine walls.

In many cases, especially in northern Appalachia, the content of alkalinity in the mine water is not equivalent in amount to the ferrous sulfate content, and the dissolved iron is only partially eliminated from solution upon aeration of the drainage. A basic reason for this imbalance is that the solubility of the sulfates causing acidity greatly exceeds the solubility of the bicarbonates contributing alkalinity, but other factors related to the particular mine environment also influence the situation. In addition to the insufficiency of carbon dioxide in shallow mine water, there often is not enough residence time of drainage water in the mine for maximum reaction with calcareous minerals. Also, there is often insufficient calcium in the overburden.

In any event, the ferrous sulfate not eliminated by alkalinity remains in solution and oxidizes to ferric sulfate on exposure to aeration, causing the drainage to become acidic. This usually occurs only after the drainage reaches an established watercourse.

For a number of reasons, however, it is not likely that the oxidation reaction would actually require the consumption of sulfuric acid as indicated in equation 2. First, no more than a possible trace of free sulfuric acid is present in fresh unaerated mine drainage effluent, as has already been discussed; the pH is generally between 5 and 5.5 unless aluminum is in solution. Second, the addition of sulfuric acid to mine drainage or any similar solution of ferrous sulfate retards rather than accelerates the oxidation. Third, the oxidation of ferrous sulfate is accompanied by an increase rather than a decrease in active hydrogen ions or acid, and is also accompanied by the precipitation of ferric hydroxide. The following equation^{*/} therefore seems to represent a more logical illustration of the oxidation of ferrous sulfate in mine drainage, as it is known and observed both in the field and in the laboratory:



Ferric sulfate in mine drainage causes the drainage to be intensely acidic. Hydrolysis releases active hydrogen ions and poorly dissociated complex residual ions into solution, producing a system that is highly buffered. As some hydrogen ions are neutralized by contact with basic minerals in the stream bed or by admixture with alkaline waters, others are released and so maintain the acidic nature (low pH) of the drainage.

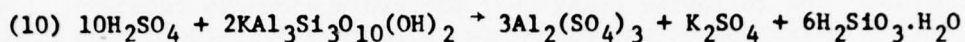
Dilution by water that does not contain significant amounts of alkalinity merely promotes more hydrolysis and the release of additional active hydrogen ions, aggravating the acidic nature of the affected waters. This situation has been observed to occur in acidic impoundments during high flow periods in early spring, at which time the concentration of ferric sulfate is low, but there is increased active hydrogen ion content. Such waters are readily subject to neutralization, and, as neutralization occurs, the ferric sulfate slowly releases all of its acidity, equivalent in total amount to the sulfuric acid shown in equation 3, although the release is recognized to be gradual.

Aluminum sulfate in mine drainage has acidic chemical properties similar to those of ferric sulfate. Aluminum sulfate is brought into solution predominately at the site of pyrite oxidation, when calcareous minerals are not available in the immediate vicinity to neutralize all of the sulfuric acid formed. The acid corrosively attacks the more resistant rocks and shales. Mine drainage resulting from the situation is highly concentrated and acidic. The elements of particular consequence in such mine drainage are aluminum, additional iron, and manganese. Major amounts of magnesium, calcium, and silica, and lesser amounts of sodium, potassium, and other elements also become soluble from the mine rock, but are not of as great consequence as the acidic pollutants. The most objectionable compounds in such mine drainage are the iron and aluminum

^{*/} Alan M. Bateman, Economic Mineral Deposits, Second Edition, John Wiley & Sons, Inc., New York, 1950, p. 247.

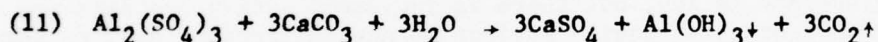
sulfates; the pollutional potential in acid mine drainage is directly related to the concentration of these two substances in solution. Manganese does not cause low pH, and remains a problem only in instances of water supply for domestic use.

The chemical action of sulfuric acid on non-calcareous shale minerals, producing aluminum sulfate, can be illustrated by the reaction with mica, which is related to the common shale mineral illite in the following chemical equation:



Aluminum sulfate in mine drainage causes the drainage to be acidic from the outset, in contrast to ferrous sulfate which requires oxidation before becoming acidic. Aluminum sulfate in drainage hydrolyzes in solution as does ferric sulfate, with the resulting acidic drainage being capable of further direct reaction with calcareous minerals and rock. When there is sufficient calcite in the mine rock, and sufficient residence time of the drainage in the mine to allow thorough contact and reaction, no aluminum sulfate remains in drainage flowing from the mine into surface waters. The aluminum is precipitated as the colloidal hydroxide, and neutral calcium sulfate is the solute product. Carbon dioxide is also released, and can further dissolve calcite to increase the alkalinity of the mine drainage, as previously described.

The reaction between aluminum sulfate in mine drainage and calcite in the mine rock proceeds as follows:



When there is insufficient reaction with calcite in the mine environment, aluminum sulfate remains in the mine water and appears in drainage from the mine. Further dilution with surface water promotes hydrolysis and increases the acidic reaction. The hydrolysis of aluminum sulfate is similar to that shown in equation 3 for ferric sulfate.

13. INFLUENCE OF SURFACE ENVIRONMENT ON MINE DRAINAGE COMPOSITION

Mine drainage which is exposed to the atmosphere and at least partially aerated and oxidized has different characteristics than that which is out of contact with air, as when confined in deep underground mine pools, or deep beneath the surface of mine spoils and mine waste piles. When confined underground, the most reactive substances in mine drainage are aluminum sulfate and dissolved carbon dioxide. An acid reaction below pH of about 4.8 in fresh, unaerated mine water indicates the presence of an appreciable concentration of aluminum sulfate in solution. This substance is chemically unstable, progressively releasing acid ions that are neutralized by alkalinity or on contact with basic minerals. Unless it escapes in drainage from the mine,

aluminum sulfate is converted underground to other more stable sulfate salts. When aluminum sulfate is not present in the mine drainage, the pH of the unaerated mine water is usually found to have a value of about 5.0 or higher.

Unaerated mine water typically has a high content of dissolved carbon dioxide and ferrous iron. On escaping to the surface, or on exposure to aeration in the mine, the drainage becomes unstable in the new environment, causing further chemical changes to take place, involving the loss of carbon dioxide and precipitation of iron. The rate of the chemical changes is strongly influenced by temperature and concentration. The most rapid changes take place during summer months when drainage concentration is high and drainage temperature rises sharply on exposure at the surface.

Mine drainage which contains ferrous sulfate in excess of alkalinity undergoes a marked drop in pH on aeration as the ferrous iron is oxidized to the ferric state. Simultaneously, ferric hydroxide is precipitated. To the extent that calcium bicarbonate alkalinity is present, iron is eliminated by aeration without a drop in pH, and the neutral product, calcium sulfate, remains in solution. These changes indicate the initial step toward improvement in drainage water quality. Acidic drainage after aeration is much more chemically reactive than is fresh unaerated drainage, and it is more amenable to rapid neutralization.

Iron-oxidizing bacteria that are found in most mine drainage water exposed to air promote oxidation of dissolved ferrous iron. They also remove colloidal ferric hydroxide from the system by entrapment in mucous slime, accelerating the reaction illustrated by equation 9. The resultant low pH sets the stage for more rapid and complete neutralization along a shorter reach of the stream. Neutralization, in effect, consists of substituting calcium or other basic ions for acid ions in solution. This process is essential for the complete elimination of dissolved ferric iron and aluminum from aerated mine water, and to raise the pH to a level tolerable to aquatic life. Thus while iron oxidizing bacteria have the obvious effect of lowering the pH of mine drainage, the total acidity is not influenced, and neutralization in the stream is more rapid.

14. OXIDATION AS A FUNCTION OF TIME IN DEEP AND SURFACE MINES

Caving and subsidence of the overlying rock strata occur in time in all Appalachian deep mines. Oxidation of fresh pyrite progressively exposed to the mine air by caving causes production of pollutants in mine drainage for many decades after some mines are closed. Similar long term effects appear to result from surface dumps of deep mine wastes containing major amounts of pyritic materials.

An entirely different situation occurs in the case of surface mining for coal. All of the rock containing pyrite is disturbed

initially and exposed to atmospheric weathering, but it is also mixed with rock that may provide some neutralization. The most intensive production of pollutant salts in drainage occurs in the first year, or in some cases, during the first two or three years, after the mining operation. In the mined land, the most intensive oxidation occurs at and near the spoil surface, with oxidation proceeding more slowly at greater depths. When and if the land surface is stabilized by proper grading to prevent erosion and exposure of more pyrite to intensive surface oxidation, the production of acidity and pollution diminishes with the passage of time.

The change in the rate of soluble salt pollutant production in drainage from strip mines can be expressed in terms of half-life, or the time required for output to drop to one-half the original production rate. On this basis, it was recently determined that spoil materials which produced the largest amounts of soluble salts, initially averaging about 45 tons per acre per year, had a half-life estimated at 3 to 4 years, while materials of a less polluttional nature, averaging less than 10 tons per acre per year, had a half-life of 6 to 8 years.*/ Thus it appears that both the total production and the rate of production of soluble salt pollutants from strip mines diminish through time, often with the worst offending sites showing the most rapid improvement.

15. WATER QUALITY CRITERIA AND THE MEASUREMENT OF POLLUTION

Water quality is measured, or may be measured, in terms of general characteristics as well as specific substances in the water. The general characteristics include acidity, pH, hardness, suspended solids, and dissolved solids. Such characteristics do not identify specific substances present, but only reflect the observed influences on water properties. They are generally useful in considering whether water is suited to certain uses or is in need of treatment before such use.

Acidity is often considered to be equivalent to pH, but it is defined specifically as the capacity for neutralizing alkalinity. Acidity in water quality is a titration measure of the capacity of a water to react with a standard alkali solution added to reach a given pH level. The levels most commonly recorded are pH 4.5 and 8.3, a range based on the bicarbonate system of alkalinity. The U.S.

*/ J. P. Vimmerstedt and P. H. Struthers, "Influence of Time and Precipitation on Chemical Composition of Spoil Drainage," Preprints, Second Symposium on Coal Mine Drainage Research, Mellon Institute, Pittsburgh, Pa., May 14-15, pp. 152-163.

Geological Survey*/ has suggested that the neutral point, pH 7.0, would seem a more logical end point**/ for titration, and includes this measurement in recent water-supply reports.

However, titration to pH 8.3 is necessary for comparing present water quality with past records. To detect historical trends, total dissolved solids should also be determined and, in addition, separate tests should be made to measure ferrous and ferric iron, aluminum, calcium, magnesium, manganese, and sulfate. Of all of these, measurement of sulfate concentrations is most useful although, unfortunately, past records have not uniformly reported the strength of this ion. Sulfate concentration is an excellent proxy for measurement of total acidity in a stream even after natural neutralization by alkaline waters. For a more detailed discussion of the utility of always determining sulfate concentrations, see Attachment A, pp. 253-257.

None of the common end point measurements have any special significance relative to mine drainage, except that pH 4.5 closely approximates the level above which both ferric and aluminum ions are eliminated from an aerated solution. Braley***/ observed that above pH 6.4 the alkalinity of mine drainage always exceeds the acidity, as measured by his special procedure.

Since the practical purpose of acidity measurement of acid mine drainage polluted waters is to estimate the neutralization needed, measurements to the minimal acceptable pH level would seem logical. This minimum is pH 5.0 by Ohio River Valley Water Sanitation Commission standards, although it is recognized that a higher pH level may be desirable if the purpose is for optimum fish propagation.

With regard to mine drainage pollution, the pH level of critical concern appears to be in the neighborhood of 4.5. This is the end point used by the United States Geological Survey in Plate II to delineate

*/ John D. Hem, Study and Interpretation of the Chemical Characteristics of Natural Water, U.S. Geological Survey Water-Supply Paper 1473, U.S. Government Printing Office, Washington, D.C., 1959, p. 99.

**/ End points are different pH levels achieved in the titration of water; pH 7.0 is considered to be chemically neutral.

***/ Silas A. Braley, op. cit. pp. 272-3.

streams that have critical acid mine drainage problems.* / When mine drainage has been aerated and neutralized to the end point of pH 4.5, virtually all of the iron and aluminum will have been precipitated as shown in Figure III-1.** / Below pH 4.5, dilution of water containing mine drainage effluent will not be as effective in ameliorating the adverse impact of the acidity. When hydrolysis occurs in streams without appreciable neutralization by basic minerals or alkalinity, the pH may drop to extremely low levels. Values below 2.0 have been recorded. The situation occurs in the early spring in certain watersheds where there is little natural limestone for neutralization. Such waters are highly corrosive because of their high reactivity.

Above pH 4.5, dilution will improve water quality through reduced concentration of the acidity. Usually the detrimental effect of mine drainage lessens as it moves downstream through contact with basic minerals in the stream bed and inflow of alkaline ground water or tributaries. Normal forms of aquatic life are almost instantly killed in water with a pH of less than 4.5. As an example, a tributary stream may bring a "slug" of acid drainage into a larger stream containing game fish. If the "slug" does not pollute more than a portion, say one-half, of the width of the larger stream, the fish can escape to the unpolluted water.

* / Plates I and II (See pages C-43 and C-45) give an indication of stream degradation resulting from mining activities. The measurements were made at the point sources along the streams and generalizations were made from the measurements about the stream lengths involved. Therefore, discrepancies between the plates exist. Additionally, different criteria are utilized by the different agencies compiling the data. The data are also collected on a sampling basis, so it is to be expected that because of seasonable factors different measurements would be obtained each time samples are collected. In this sense, some FWPCA data on Plate I may be more indicative of continuing stream quality than is the case with the USGS data on Plate II because the FWPCA information represents averages of a series of data. This apparently was not always the case of measurements of pH level by USGS. Probably the biggest discrepancy is in the upper Ohio River. The Ohio River below Pittsburgh rarely has a pH reading as low as 4.5 as shown on Plate II. However, Plate II is included because it generally reflects those areas where critical acidic water quality problems exist for all aquatic uses, most municipal uses, and many industrial uses. Even with correction of the discrepancies, the plates may not be entirely complete or accurately reflect current stream conditions.

** / The neutralization curve in Figure III-1 reflects an analysis of five mine drainage samples having an acidity range of 1300 to 9300 parts per million.

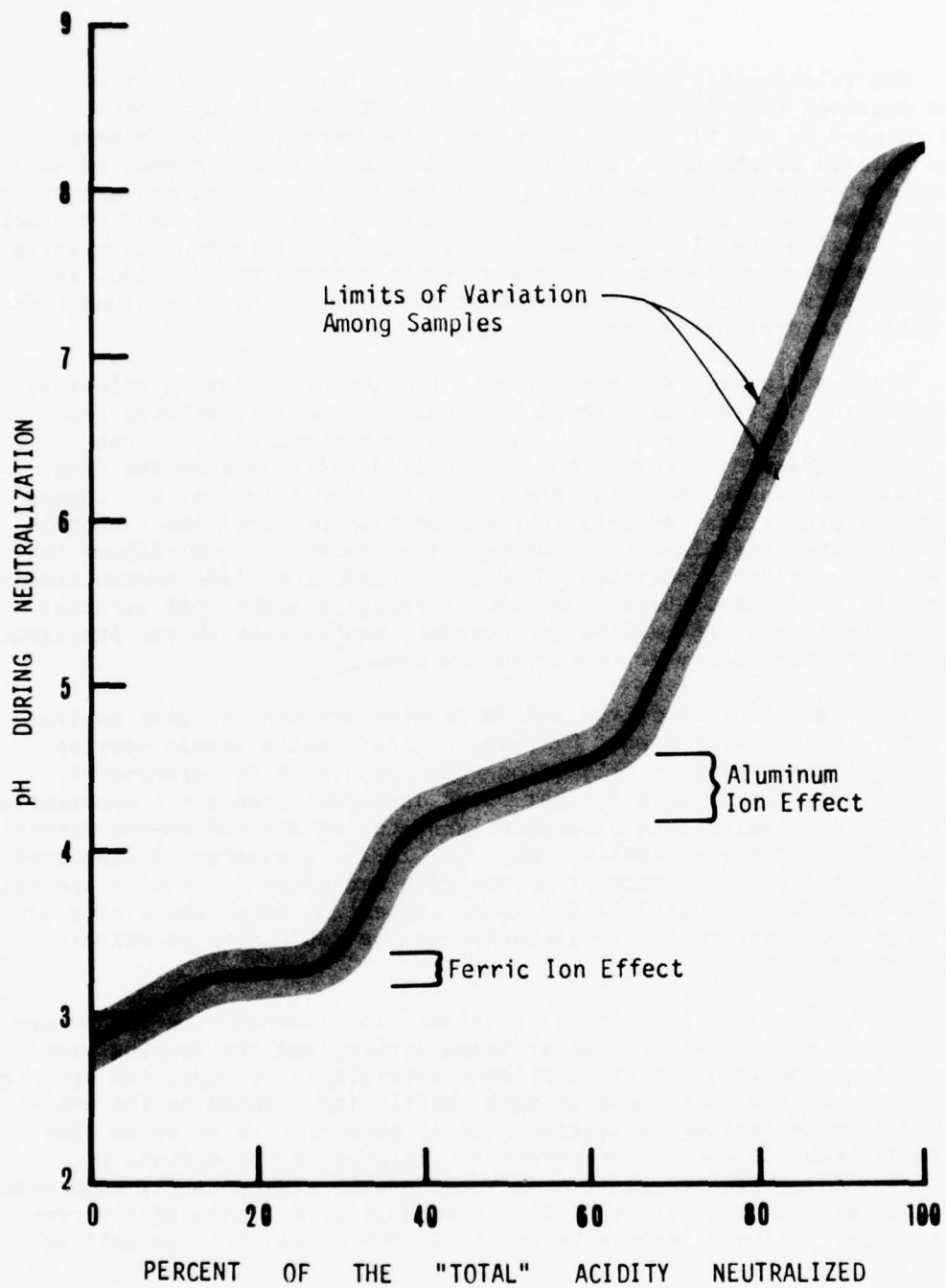


Figure III-1 Aerated Mine Drainage Neutralization Curve

The relationship between alkalinity and hardness is different in mine drainage than in ordinary surface waters where both properties are related to the bicarbonate content. Hardness in mine drainage is also related to the sulfate content. Since much of the dissolved sulfates may be present other than as calcium and magnesium, measurement of hardness by the older soap-consumption method is more relevant to practical evaluation than is measurement by the EDTA^{*/} titration. The latter method is often subject to serious error in routine application, requiring special precautions to prevent interference by other ions present in acid mine drainage waters.

Whereas standard water treatments by lime softening is effective in reversing bicarbonate-related hardness, the sulfate-related hardness content, from a practical, municipal-use standpoint, is not seriously affected. Conversion of dissolved sulfates from the iron, aluminum, manganese, or acid form to the calcium form does not change water-use properties, such as soap consumption or total ionic content, which affects domestic use. However, lime treatment does relieve the undesirable acidic properties. Thus, the claim that lime neutralization increases hardness is based upon the technical concept that hardness is dependent upon the calcium ion content, rather than on the practical concept of suitability for water supply use.

Measurement of dissolved solids in mine drainage is also subject to error in interpretation. Different sulfate salts retain varying amounts of water of crystallization when evaporated for gravimetric measurements, the amounts further being dependent upon the temperatures used. Thus, results from different laboratories are not always directly comparable, and are generally high. Similarly, estimates of dissolved solid content by resistance or conductance measurements require special calibration curves suited to the ionic content of water containing mine drainage. Conventional interpretation may be subject to relatively large errors.

The requirement for special consideration in measuring and interpreting the properties of mine drainage waters, and the varying viewpoints and objectives of the different disciplines, groups, and agencies concerned point up the cause of much conflicting opinion in the evaluation of mine drainage pollution. It is generally to be noted that there is less subjective interpretation related to the effects of specific, identified chemical substances present in the water than when broad water quality characteristics are considered. Essentially complete water analysis records by the USGS, FWPCA, and TVA, as well as

^{*/} Ethylenediaminetetraacetic acid.

from other public and private sources, are available for many stream reaches in the Appalachian Region. However, a more concerted and critical effort at interpretation of such data is needed to achieve better understanding and evaluation of water pollution by mine drainage.

16. INFLUENCE OF SEASONS ON MINE DRAINAGE POLLUTION

Precipitation is reasonably well distributed throughout the year in the Appalachian Region, but the amount of water infiltrating the ground and causing mine drainage varies markedly with the seasons. The amount of water passing through a mine in most instances does not appreciably influence the amount of pyrite oxidized. To a limited extent, water flowing rapidly into and through a mine may contribute oxygen and promote some oxidation, or conversely, rising water may inundate pyrite and prevent oxidation. For the general case, however, the rate of pyrite oxidation in Appalachian mines is not dependent on the amount of liquid water present. Pyrite oxidation for all practical purposes may be considered as continuous, while drainage flow is variable through the year. The amount of water reaching a mine in a given season directly influences the volume of mine drainage produced during that season. The mine water acts chiefly as a transport agent, dissolving and carrying soluble substances from the mine into surface streams.

In the summer, most rainfall occurs as thunderstorms. The annual number of thunderstorm-days ranges from about 30 in parts of Pennsylvania to about 60 in Alabama.*/ Summer storm rainfall is usually intense, with rapid surface-water runoff from unvegetated smoothly graded and sloping mined areas and mine wastes causing severe hydraulic erosion and stream sedimentation. Sediment production as much as 1000 times more than that from undisturbed forest land has been measured.**/

Summer storm runoff also carries surface accumulations of soluble pollutants into streams during the low flow season. Detrimental effects on aquatic life are intensified by the sudden increase in solute concentrations and the prevailing high temperatures. Extensive fish kills have sometimes occurred, caused by concentrated "slugs" of acidic drainage

*/ William J. Schneider, et. al., op. cit.

**/ U.S. Department of the Interior, op. cit., p. 63.

runoff which carry far downstream after unusually heavy local thunderstorms in the summer.*/

Winter precipitation is more gentle and the amount of infiltration is greater during the dormant season. As a result, there is an excess of ground water from about December through April, increasing the amount of effluent drainage and seepage from both underground and surface mines during the season.

The major production of dissolved constituents in drainage from mines occurs during the winter and early spring months as shown in Figures III-2 and III-3.**/ However, the polluttional effects on stream water quality and on aquatic life are less at that time of year because of the prevailing higher stream flows, lower stream concentrations, and lower water temperatures.

The complete annual cycle is illustrated in Figure III-4, based on average soil-moisture conditions in the Pittsburgh area. Seasonal variations in rain infiltration cause the seasonal differences in mine drainage shown in Figures III-2 and III-3. The flow of drainage from mines and, therefore, the volume of dissolved constituents entering the streams are greatest in the winter and reflect periods of rain infiltration and ground water movements. The quantity of mine drainage produced during the remainder of the year is relatively less.

Concentrations of solutes in mine drainage are generally highest in the first flush of drainage produced after dry periods during which solutes accumulate in the mine. Increasing concentrations are also related to protracted periods of decreasing flow, usually between May and October, but sometimes extending into winter. While concentrations increase during the summer and fall, flows are generally reduced at a relatively greater rate so that the net amount of solutes in drainage from mines progressively decreases during that period. This relationship is shown in Figure III-5. In the figure, acidity concentrations observed over a period of five years in drainage from a single mine in Pennsylvania are contrasted with the amounts of acidity produced by seven mines during a one-year period. The figure shows an inverse relationship between mine drainage acidity amounts and concentrations during the period April to November.

Increasing mine drainage concentration occurs also in the receiving streams during the summer, causing increased polluttional effects. Concentrations in the streams generally increase from about June through September, reflecting an inverse relationship with total stream flow.

*/ Pennsylvania Department of Public Health, Report on Pollution of Slippery Rock Creek, Publications No. 8 (January 21, 1965) and No. 17 (April 1966).

**/ Used with permission of the U.S. Department of Interior, Bureau of Mines.

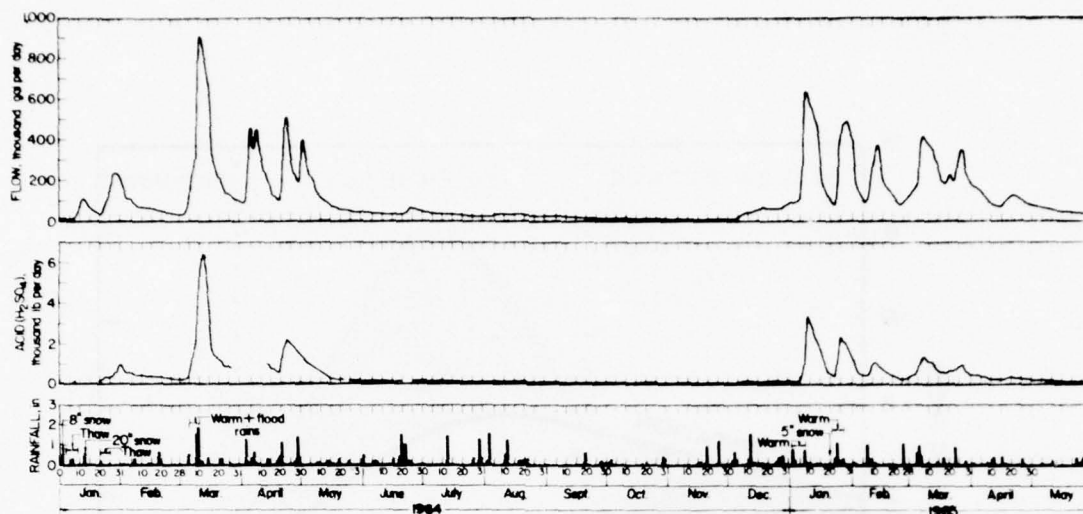


Figure III-2 Influence of Season and Precipitation on the Flow and Titrable Acidity Content of Coal Mine Drainage.

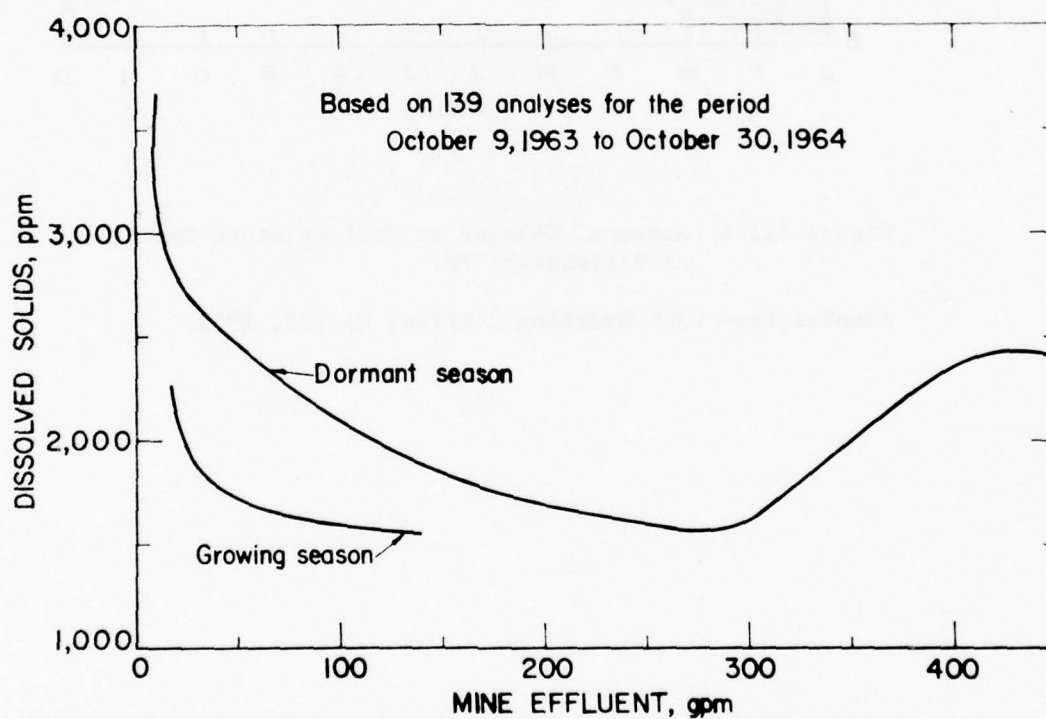


Figure III-3 Relationship Between the Flow and the Concentration of Coal Mine Drainage During Different Seasons.

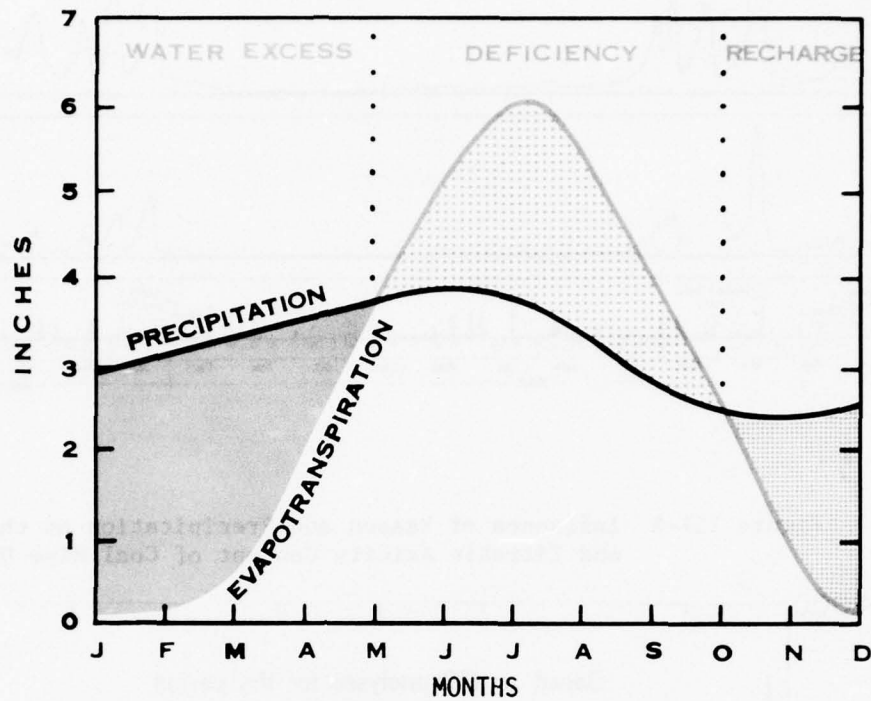


Figure III-4 Seasonal Changes in Soil-Moisture Conditions at Pittsburgh, Pa.

Adapted from USGS Hydrologic Atlas, HA-198, 1965.

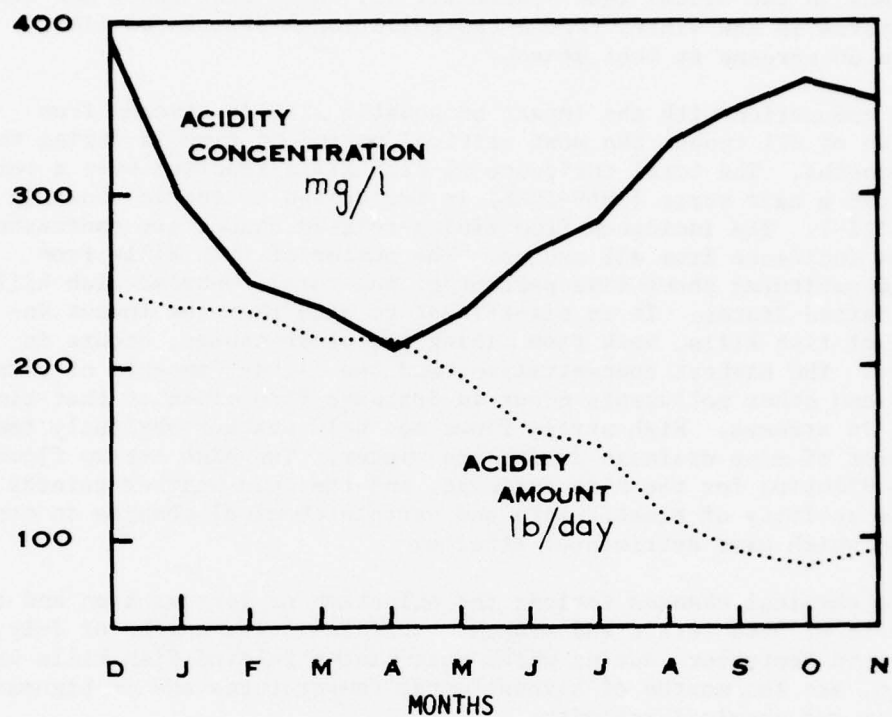


Figure III-5 Influence of Season on Mine Drainage Acidity Concentration and Amounts.

Source: Silas A. Braley, Op. Cit., 1954.

The summer and early fall months are most critical from the standpoint of mine drainage as well as other types of pollution in streams because of low flow. The seasonal relationship between stream flow and pollution from mine drainage, as indicated by sulfate concentration, is illustrated in Figure III-6. The highest concentrations of mine drainage in streams occur in late summer, although a greater total amount of solutes drain from mines in the winter (See Figure III-5). High flow rates and cold temperatures in the winter reduce the pollutional effects of mine drainage on streams at that season.

In connection with the impact on aquatic life in streams from pollution of all types, the most critical period of time is during the summer months. The total incidence of fish kills reported over a period of six and a half years (1960-1966) in the United States is shown in Figure III-7. The incidence from mining-related causes are contrasted with the incidence from all causes. The number of fish kills from mining constituted about five percent of the total reported fish kills in the United States. It is significant to note that the lowest incidence of fish kills, both from mining and other causes, occurs in December. The highest concentrations and the highest amounts of total acidity and other pollutants occur in drainage from mines at that time, but not in streams. High stream flows and cold weather obviously temper the impact of mine drainage during the winter. The high stream flows provide dilution for the mine drainage, and the cold weather retards both the activity of aquatic life and certain chemical changes in mine drainage which have detrimental effects.

The chemical changes include the oxidation of ferrous iron and the hydrolysis of both ferric and aluminum sulfates. The months of July, August, and September, during which most mining related fish kills have occurred, are the months of highest water temperatures and of highest metabolic and chemical activity.

It is also during the summer months that heavy rainfall occurs in thunderstorms, accompanied by a high rate of surface runoff into the streams rather than infiltration into the land surface. Where the runoff occurs from surface mined lands or from mine waste deposits, both soluble and solid wastes are carried into streams, contributing "slugs" of pollution which have detrimental effects far down stream beyond the usual range of effect.

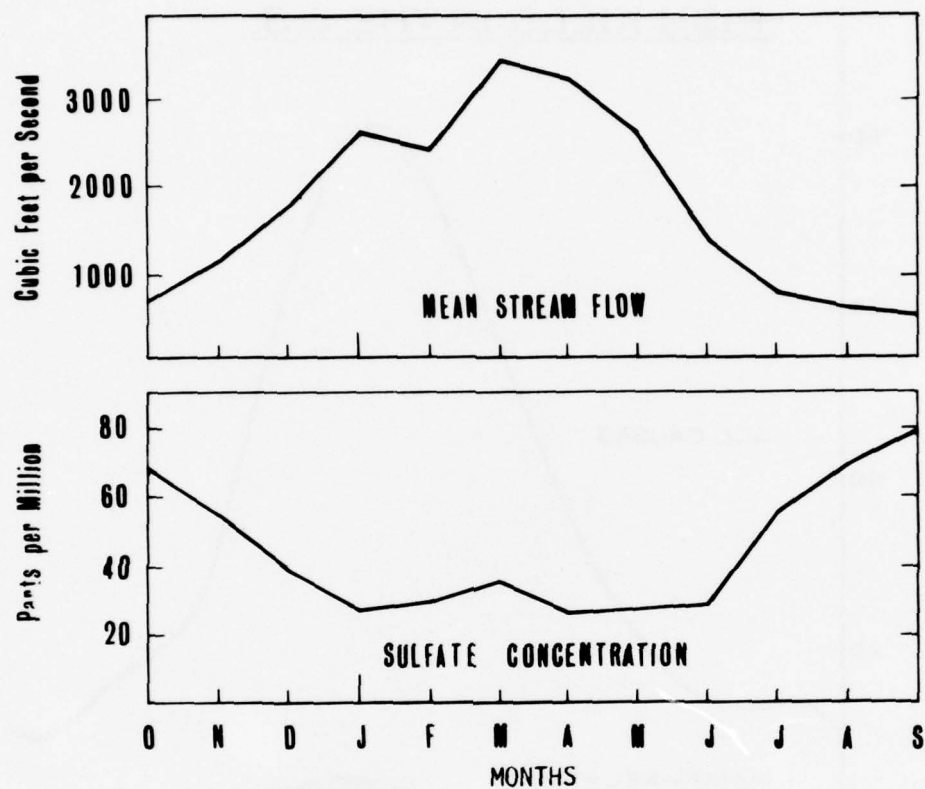


Figure III-6 Influence of Season on Stream and on Mine Drainage Pollution as Indicated by Sulfate Concentration, Clarion River at Piney, Pa.

Source: USGS Water Supply Paper, 1835.

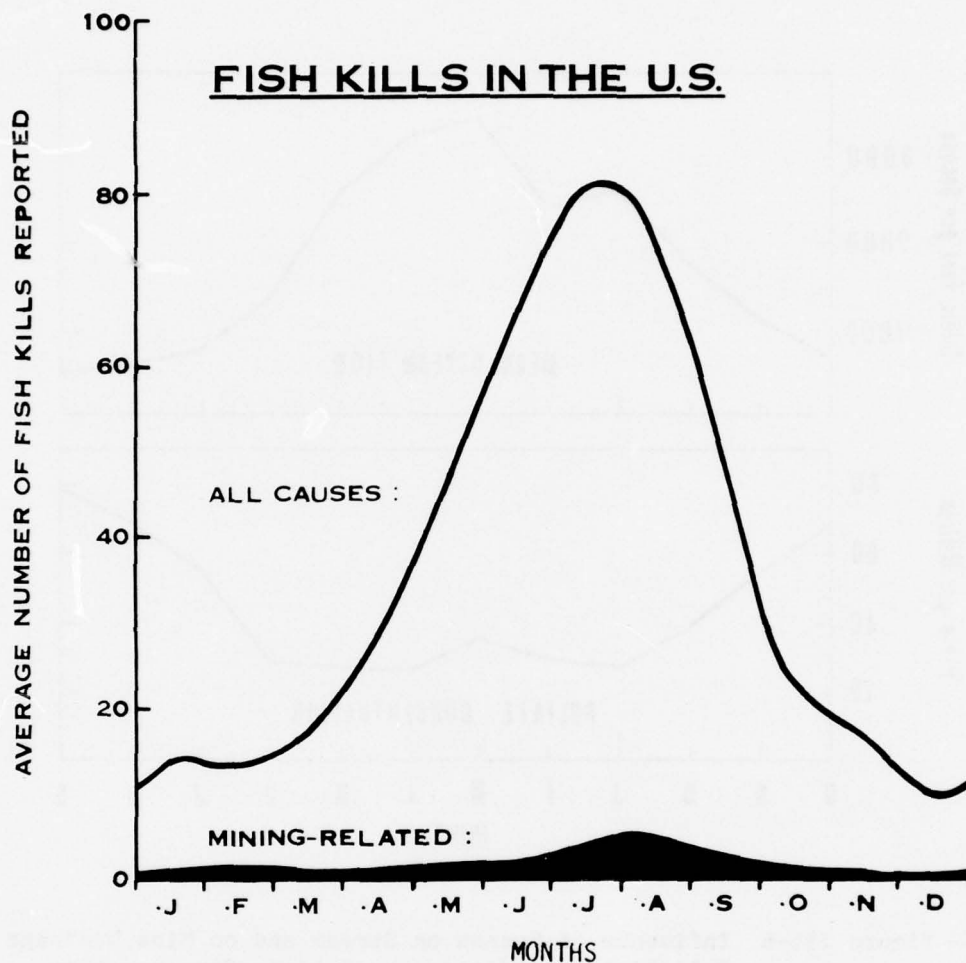


Figure III-7 Influence of Season on Incidence of Fish Kills, June 1960-December 1966.

Source: Department of Public Health (1960-1965), Federal Water Pollution Control Administration (1966), Fish Kills By Pollution 1960-1966, Annual Publication, U.S. Government Printing Office, Washington, D.C.

SECTION IV - WATER RESOURCE DEVELOPMENTS ON MINE DRAINAGE POLLUTED STREAMS

17. FUTURE ABATEMENT EFFORTS

The findings and conclusions of the Appalachian Regional Commission do not provide a basis to support a massive attack throughout Appalachia to abate mine drainage pollution from inactive mines. However, the Commission does find that, in a valley that has been selected for environmental improvement, improving stream quality may be one of the essential steps to transform the area so that it will attract private investments in recreation, industry or housing. These findings suggest that programs to abate mine drainage pollution, although expensive, can be justified selectively where they will pay off in helping to trigger major change in the use of the land and its waters. Otherwise, one must assume that water pollution from inactive mines, at the locations reported in Attachment A, will continue for some time. Future abatement efforts, using the techniques described in Attachment E (and in Appendix A to the Commission's report), will gradually reduce the extent of the Region's problems, but only gradually.

18. WATER PLANNING GUIDELINES

In planning for water resource investments in Appalachia, the above suggests two guidelines. First, there is no foreseeable advantage in delaying installing a system of water management structures until some date when Appalachia's streams will be unpolluted and brimful with fish; if a flood control reservoir is needed and feasible, the fact that the flooding river is polluted should not hold up the needed construction. On the other hand, the planning and construction agencies should carefully evaluate the costs and benefits of abating the mine drainage pollution in the river as a component of the reservoir in order to produce a transformation of the environment in and surrounding the resultant lake. Several existing flood control reservoirs above Pittsburgh are so polluted by acid mine drainage that they cannot support recreation development. In these cases the costs of sufficiently abating the pollution to transform them from "dead seas" to excellent boating and fishing lakes are greatly in excess of the potential benefits to the reservoirs. However, the water development planner should always be alert to potential opportunities; the following paragraph describes a case in point.

19. THE PROPOSED ST. PETERSBURG RESERVOIR

An outstanding example of the role that mine drainage abatement can play is associated with the St. Petersburg Reservoir which is proposed for construction on the Clarion River five miles from its confluence

with the Allegheny River in western Pennsylvania. This structure is reported in Chapter 11 of Part III of the pending report, Development of Water Resources in Appalachia. The Clarion River drainage basin is badly polluted by mine drainage from past and present coal mining activities. The multiple purpose St. Petersburg Reservoir will play an important role in the economic development of western Pennsylvania because it is designed for flood control, water quality improvement, water supply, recreational activities, and hydro-electric power. Without an effective mine drainage abatement program, the Federal Water Pollution Control Administration has recommended against impoundment of the lower Clarion River because the water will not be of high enough quality for many of the project's objectives to be realized.

An effective abatement program is estimated to cost \$15 million, approximately 17 percent of the total project cost. The reclamation will include restoration of strip mined land and elimination of significant volumes of deep mine pollution effluents. Pennsylvania's water quality legislation is adequate to prevent undesirable reductions in water quality by active and future surface and deep mines.

The mine drainage abatement program necessary for the viability of the St. Petersburg Reservoir will not eliminate all of the sources within the Clarion River basin, but it will ameliorate a presently untenable situation in a specific area with high growth potential. The remaining pollution sources from inactive mines do not produce enough pollutants, or are too isolated, to have a serious impact upon the reservoir.

APPENDIX C
THE INCIDENCE AND FORMATION OF MINE DRAINAGE POLLUTION

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APPENDIX C
THE INCIDENCE AND FORMATION OF MINE DRAINAGE POLLUTION

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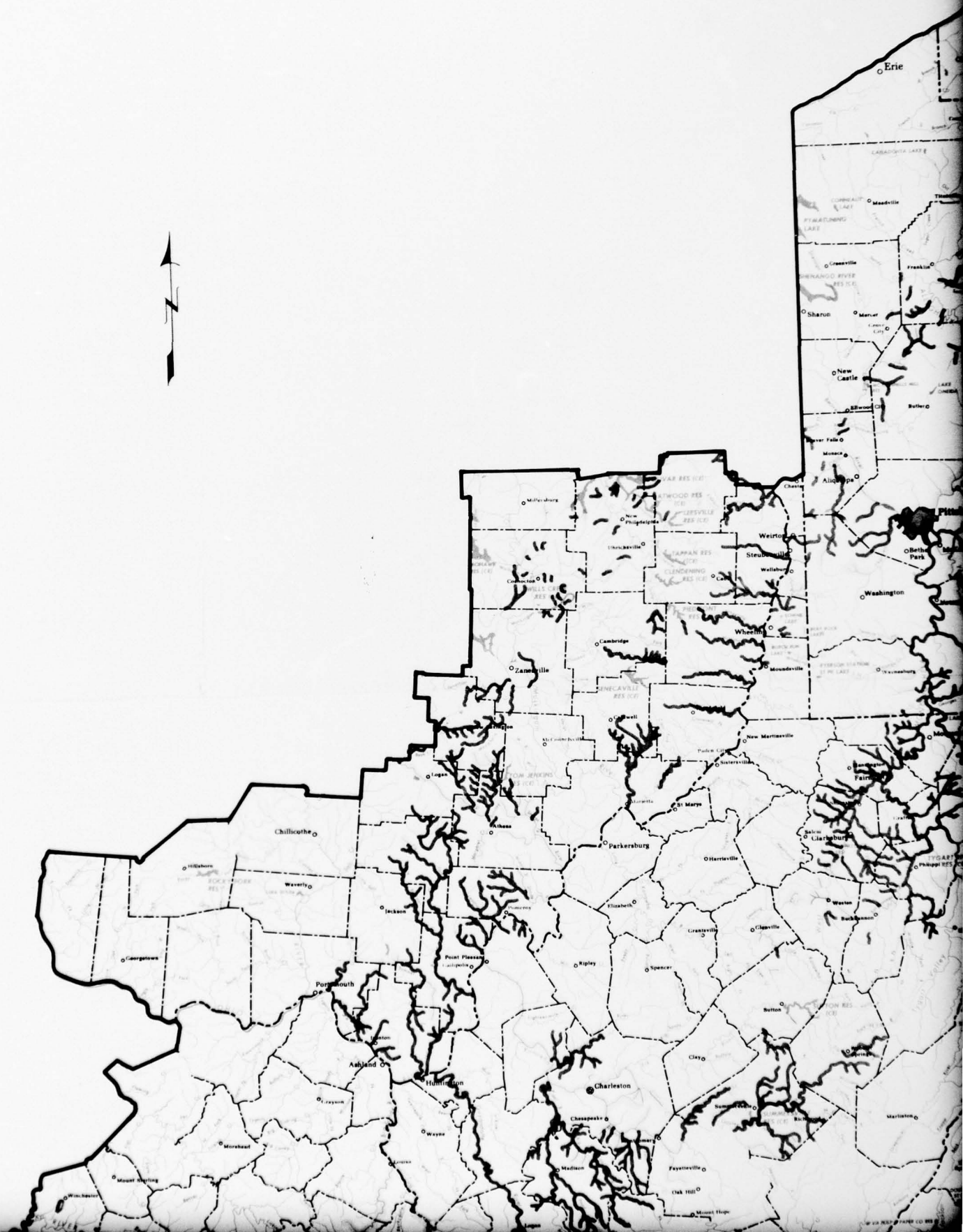
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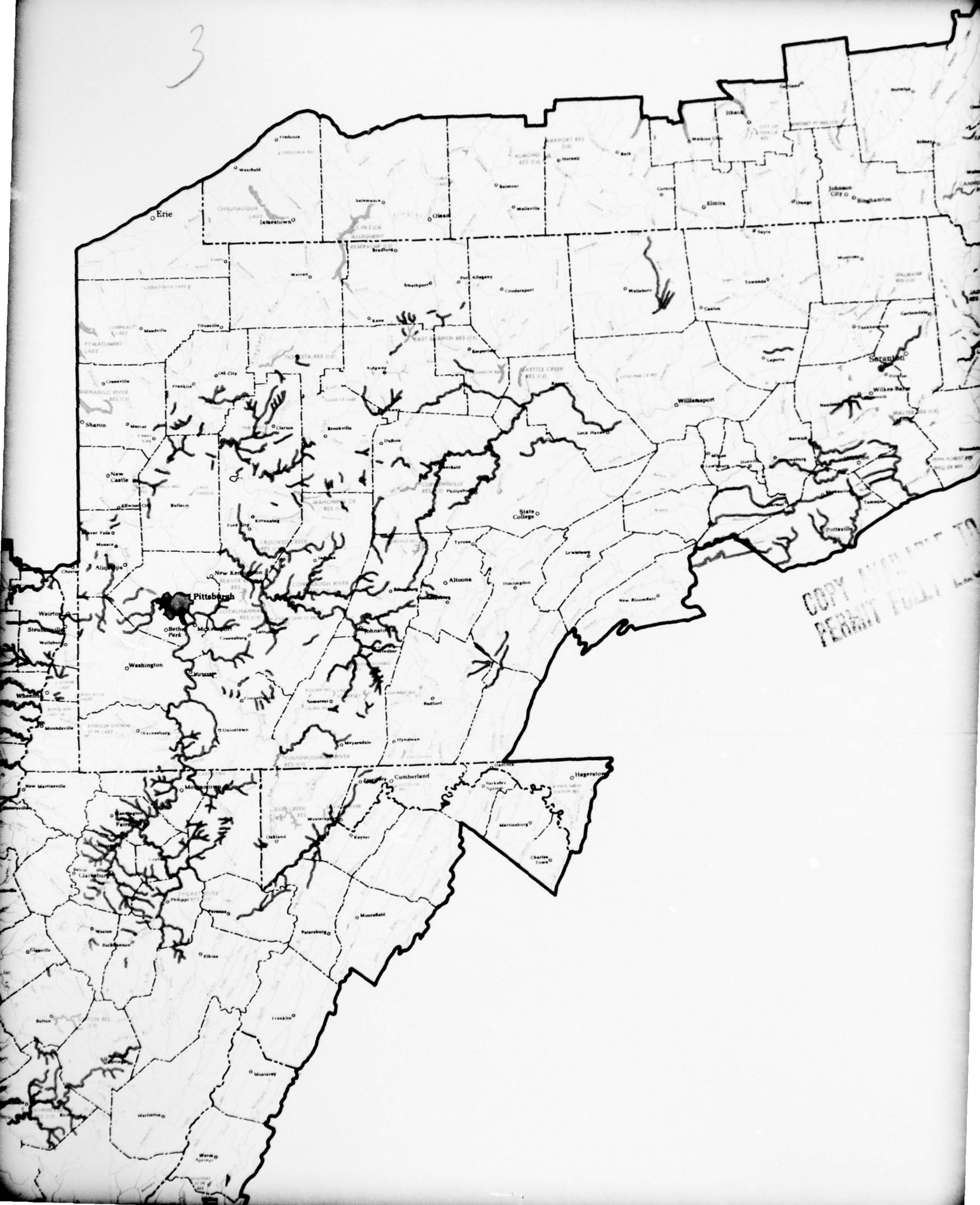
<u>Water Quality Characteristics</u>	<u>Limiting Parameter</u>
1. pH	Less than 6.0
2. Acidity and Alkalinity	Net Alkalinity Less than 20mg/l
3. Hardness	More than 250mg/l
4. Suspended Solids	More than 250mg/l
5. Dissolved Solids	More than 500mg/l

<u>Element or Ion Content</u>	<u>Limiting Parameter</u>
1. Total Iron	More than 1.5 mg/l
2. Aluminum	More than 0.5 mg/l
3. Manganese	More than 1.0 mg/l
4. Sulfate	More than 250 mg/l

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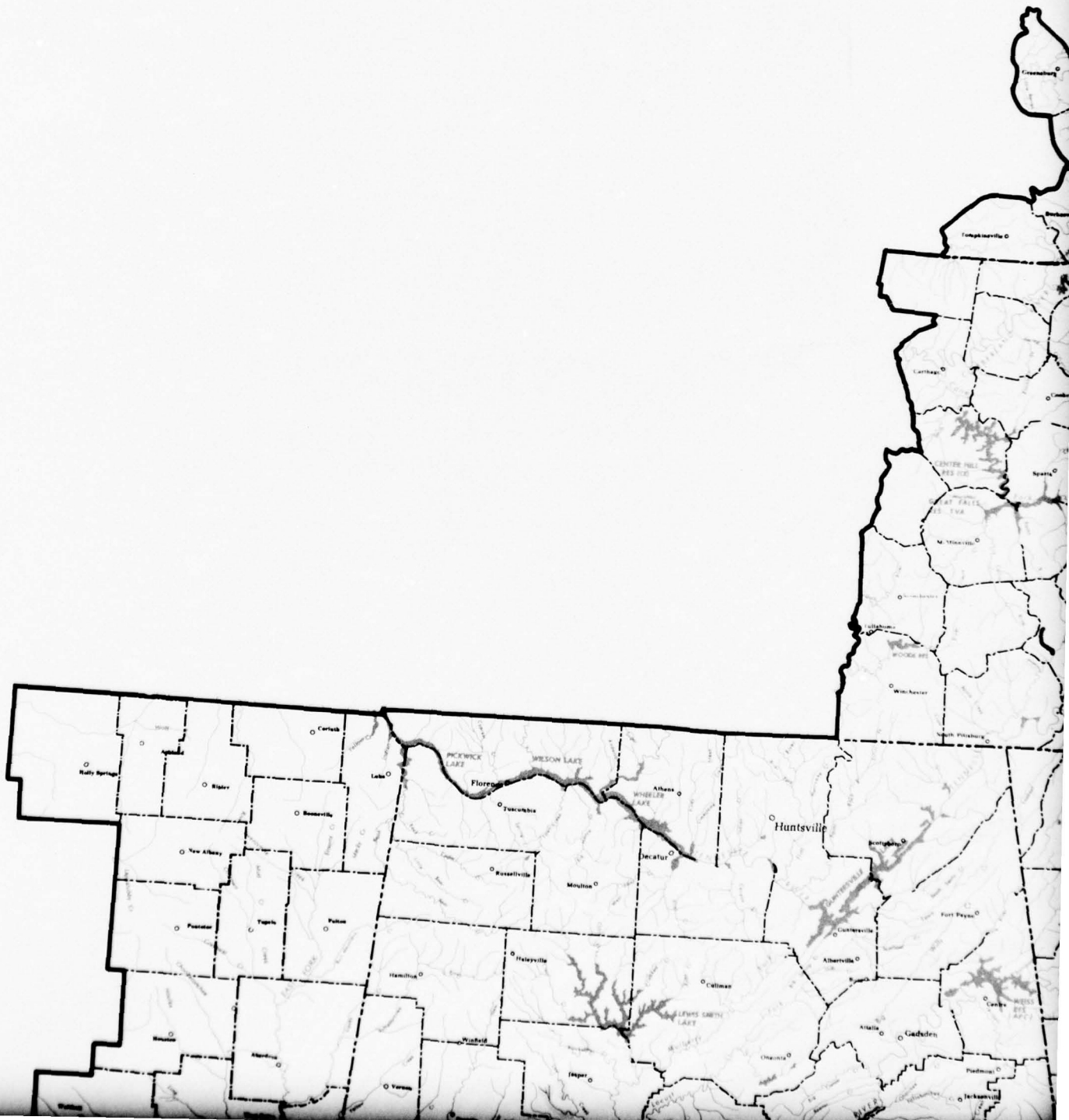




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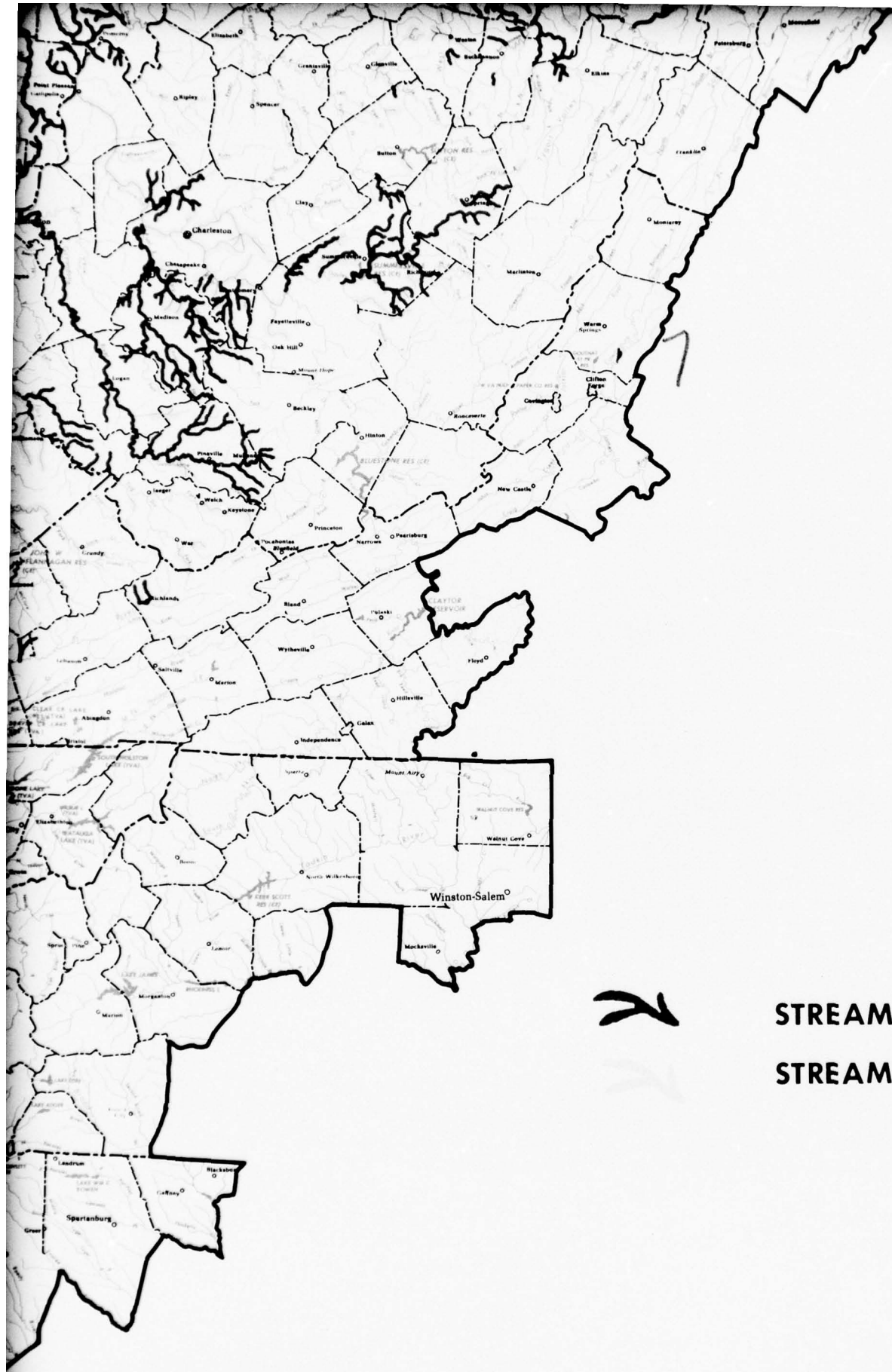
2. Aluminum More than 0.5 mg/l
3. Manganese More than 1.0 mg/l
4. Sulfate More than 250 mg/l

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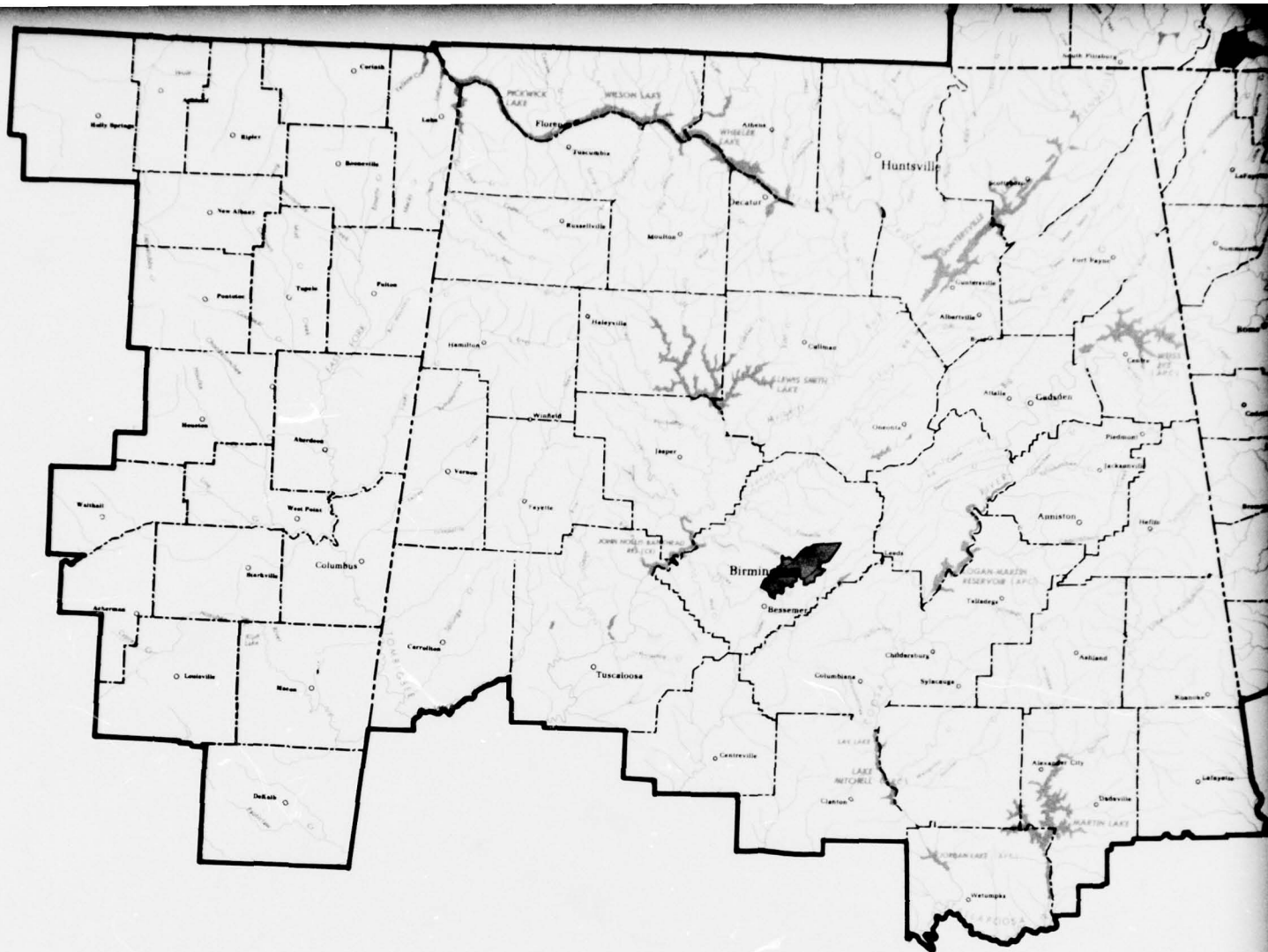
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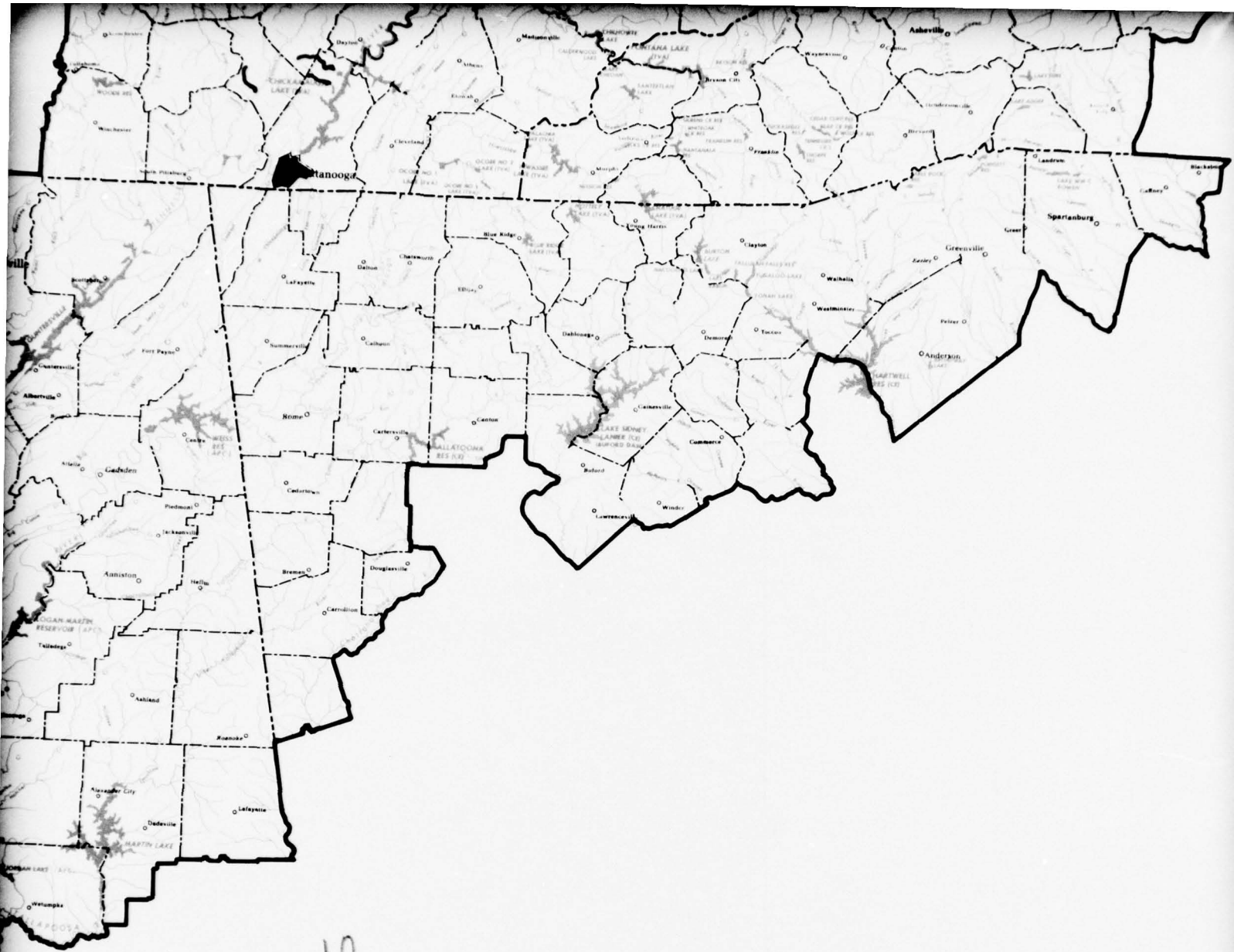
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REPORT FOR
DEVELOPMENT OF WATER RESOURCES
IN



SCALE IN MILES





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REPORT FOR
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AMS INTERMITTENTLY OR POTENTIALLY AFFECTED

SOURCE: FWPCA ATTACHMENT A

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REPORT FOR
DEVELOPMENT OF WATER RESOURCES
IN
APPALACHIA

APPALACHIAN STREAMS AFFECTED BY MINE DRAINAGE

CENTRE OF APPALACHIAN STUDIES

OCTOBER 1968

C-43

PLATE I

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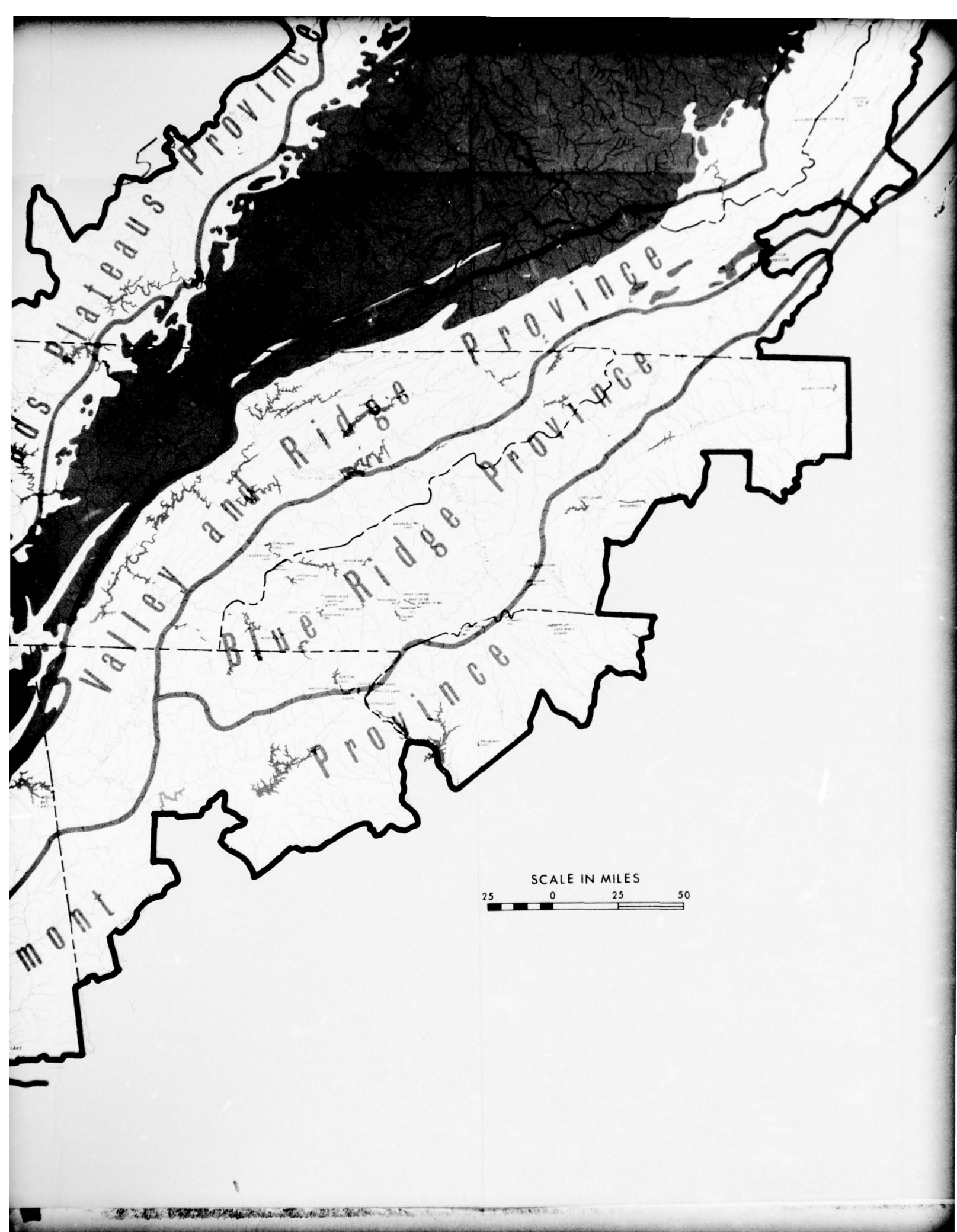


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4







NOTE:

ACID STREAMS \leq pH 4.5 SHOWN IN RED
SOURCE: US GEOLOGICAL SURVEY DATA, 1965

REPORT FOR
DEVELOPMENT OF WATER RESOURCES
IN
APPALACHIA

ACID MINE DRAINAGE IN APPALACHIAN STREAMS

OFFICE OF APPALACHIAN STUDIES

OCTOBER 1968

C-45

PLATE II

U.S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
OHIO BASIN REGION
Cincinnati, Ohio



STREAM POLLUTION BY COAL MINE DRAINAGE IN APPALACHIA

STREAM POLLUTION BY COAL MINE
DRAINAGE IN APPALACHIA

U. S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
CINCINNATI, OHIO

PREPARED 1967 and
REVISED 1969

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FOREWORD

This publication constitutes a status report of Federal Water Pollution Control Administration studies concerning the sources and extent of coal mine drainage stream pollution in the Appalachian Region and is intended to serve as a summary reference regarding those aspects of the problem.

The documentation of streams affected by coal mine drainage is essentially complete. It is based on extensive field studies done by FWPCA supplemented by information obtained from the States in the Region. Preliminary inventories of coal mine drainage sources have been completed in watersheds wherein 75 percent of the acid drainage in Appalachia originates. Inventory work in the Allegheny River basin was done cooperatively with the State of Pennsylvania. In all areas, more refined stream and source inventory studies will be required as abatement work progresses in order to allow design of specific abatement programs in the individual watersheds.

The information in this report was obtained primarily from continuing FWPCA projects. However, special effort was made to time preparation of the report so that it could be included as part of the "Development of Water Resources in Appalachia," a water resource survey authorized in Section 206 of the Appalachian Regional Development Act of 1965. During 1968 and 1969, it became apparent that information in "Stream Pollution by Coal Mine Drainage in Appalachia" would also constitute a significant contribution to the Appalachian Regional Commission study of acid mine drainage in Appalachia as authorized by the Appalachian Regional Development Act Amendments of 1967. It was, therefore, agreed that "Stream Pollution by Coal Mine Drainage" would also appear as part of an appendix to the Appalachian Regional Commission's 1969 report, "Acid Mine Drainage in Appalachia."

The cooperation of the States and other Federal agencies that provided information contained herein or assistance is appreciatively acknowledged. In particular, I wish to acknowledge the cooperation of the U.S. Army Corps of Engineers Office of Appalachian Studies in providing assistance in the drafting and printing of the report.

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INTRODUCTION

General Statement

Coal is the most abundant mineral resource in Appalachia and 75 percent of the total cumulative coal production in the United States has been from this area. Coal deposits underlie more than 72,000 square miles of Appalachia, about 40 percent of the total area.

Some discoloration of streams by the natural drainage from hillsides containing coal deposits was observed to exist by Gabriel Thomas in 1698 (Eavenson, 1942). After the advent of commercial mining, coal mine drainage stream pollution began to have serious effects, and as early as 1890, the Youghiogheny River at McKeesport, Pennsylvania, contained sufficient pollutants from coal mining activities to kill fish at times (U.S. Public Health Service, 1962). Today, pollution of streams in Appalachia by coal mine drainage may qualify as the single most significant pollution problem in terms of the severity of damage to streams and in terms of the effort that will be required in abating this pollution.

Coal mine drainage pollution as it is generally conceived of begins with the exposure of iron sulfide minerals associated with coal to the atmosphere during mining. The exposed relatively insoluble sulfide minerals are converted by oxidation to soluble sulfuric acid and to iron compounds. The sulfuric acid may in turn dissolve other minerals such as manganese, aluminum, and calcium.

The sulfuric acid, iron, and other minerals in mine drainage affect water use in various ways. To many, the most dramatic effects of mine drainage pollution are in the destruction of fish and other aquatic life and impairment to stream appearance that often occur. Mine drainage pollution may affect the use of water for municipal and industrial water supply by increasing the costs for equipment and for water treatment. Additional damaging effects of mine drainage are to increase the corrosiveness of the polluted water to boats and to dams and other structures built in the polluted streams.

Purpose and Scope

This report is intended to serve as a summary reference concerning the occurrence and sources of coal mine drainage pollution in Appalachia.

pollutants varying as a function of the volume of water entering the
time, contact time, and available reactive materials. In cases where

The general distribution of coal mine drainage pollution in Appalachia has long been known, but recent data were not available to show, in detail, the streams affected and their quality. Therefore, documentation of the extent of the problem constitutes the major part of the report. In some areas all available stream water quality data are presented; in other areas only representative data are included. In all areas, additional stream water quality and streamflow data will be required as abatement work progresses. A preliminary effort has been made to locate and describe coal mine pollution sources in those watersheds that contribute 75 percent of the acid entering Appalachian streams. This effort is sufficient to establish the relative numbers and types of sources in the various watersheds and their individual pollution contributions at the time of investigation, but much more detailed study of the individual sources will be needed to allow design of a specific abatement program in any individual watershed. Pollution sources are described here in only a broad statistical way. Descriptions of the amount and chemical quality of individual discharges and the type of mine or other source are in the files of FWPCA and State agencies and, in some cases, in more detailed reports that cover sub-areas of Appalachia.

Designs and cost estimates for specific mine drainage abatement projects are not discussed here. Such designs and cost estimates as have been prepared are primarily for watersheds in Pennsylvania, where \$150 million has been allocated for the abatement of pollution from abandoned mines. Some mine drainage pollution abatement projects that have been recommended as emergency or top priority projects in Pennsylvania are discussed in the Pennsylvania State Water Resources Supplement to the Development of Water Resources in Appalachia. Other sources of information concerning the development of abatement projects in Appalachia are the monthly Secretary's Report of the Department of Mines and Mineral Industries and Pennsylvania's Ten Year Mine Drainage Pollution Abatement Program for Abandoned Mines, which is published by the Pennsylvania Sanitary Water Board, Department of Health.

SUMMARY AND CONCLUSIONS

Data that characterize the present problem of stream pollution by coal mine drainage in Appalachia are presented in Tables 1, 1-A, and 1-B. The sub-areas of Appalachia that are listed in Table 1 are shown in Figure 1.

Table 1 lists the sub-areas discussed in the report and presents data pertinent to coal mine drainage pollution. Table 1 shows that 10,500 miles of Appalachian streams are significantly affected by coal mine drainage pollution, 6,700 miles of these on a continuous basis. Approximately 68 percent of the mine drainage acidity formed in Appalachia originates in the Monongahela, Allegheny, and Susquehanna-Delaware River basins of Pennsylvania, West Virginia, and Maryland. Forty-three percent of the affected miles of streams are in these watersheds. Significant amounts of acid drainage and consequent polluted streams occur in the Beaver, Muskingum, Hocking, Kanawha, and Big Sandy River basins and in smaller streams that are directly tributary to the Ohio River between Pittsburgh and Cincinnati. Lesser amounts of pollution exist in the other watershed areas listed, but the effects may still be significant locally.

Coal mine drainage pollutants affect water quality by lowering the pH, reducing the natural alkalinity, increasing the total hardness, and by adding undesirable amounts of iron, manganese, aluminum, sulfates, and other chemicals. Sediment is eroded from mined areas and fine coal enters streams from coal processing plants and refuse disposal areas.

Adverse effects to municipal and industrial water use are caused by the chemicals, silt, fine coal, and added color that result from coal mining and coal processing. Corrosion of boats, bridges, locks and dams, and other facilities and equipment is accelerated by acid mine drainage. Discharge of mine drainage and coal mining or coal processing wastes into streams and lakes impairs their quality for fishing and makes them unattractive for boating, water skiing and swimming, and lowers their value as a scenic resource.

The distribution of mine drainage pollution throughout Appalachia is a result of numerous factors including topography, geology, hydrology, amount of pyritic minerals present, and mining methods used. However, the present distribution of pollution is primarily a result of the amount of pyritic minerals present and the extent of mining. Intensively polluted areas are ones where mining has been extensive and where pyritic minerals are relatively abundant.

Table 1-A summarizes data for 5,570 significant sources of mine drainage pollution that have been located and described in Appalachia during 1964-1968 by FWPCA, in many instances in cooperation with the State of Pennsylvania. The watersheds that have been surveyed contribute about three quarters of the 6,000 tons/day of acid that enters Appalachian

streams. However, the total amount of acid measured at the 5,570 individual sources only amounts to about 1,600 tons/day, approximately one-quarter of the 6,000 tons/day of acid estimated to enter Appalachian streams. This large discrepancy results because source inventories were conducted primarily during the dry summer months and because there are undoubtedly many additional sources that were not located during the initial surveys that were performed.

Of the sources that have been inventoried, inactive underground mines contribute 52 percent of the acid, active underground mines 19 percent, inactive surface mines 11 percent and active surface mines 1 percent (Table 1-B). Most of the remaining sources are in combination surface-underground mines. Refuse piles and coal processing plants contribute about 7 percent of the total acid measured. Inactive sources contribute 78 percent of the acid and active sources 22 percent. A significant fact, not brought out in Tables 1-A and 1-B, is that frequently a major amount of the pollution in a particular watershed is contributed by a few sources, and that the degree of success in controlling drainage from these few sources will determine the success of an abatement program. It is apparent that the success of any large-scale mine drainage pollution abatement program will depend on the ability to control drainage pollution originating in abandoned underground mines.

Examination of the available historical stream quality data indicates that while fluctuations have occurred in mine drainage pollution loads, substantial permanent increases in acid loads do not appear to have occurred within the past 20 to 25 years. These data indicate that total pollution loads in large sub-areas of Appalachia, such as are listed in Table 1, will tend to remain in the same order of magnitude within the next few decades unless corrective measures are applied.

Although the total quantity of pollutants discharged to Appalachian streams may not be tending to increase rapidly, it is expected that the mine drainage pollution problem will become more severe in terms of the number of inactive mines contributing pollution. In addition, previously unpolluted streams will be degraded as mining advances into new areas unless effective controls are established over the opening and abandonment of new mines. The potential for further pollution from mining activities is reflected by the fact that remaining recoverable reserves of bituminous coal in Appalachia are equal to 440 times the 1964 production and seven times the total cumulative production from the beginning of mining to 1965 (Arndt and others, 1968).

Table 1 - Summary of Data Concerning Mine Drainage Pollution in Appalachia

Subarea in Appalachia	Drainage Area in Appalachia (square miles)	Mine Drainage Acidity Formed in Basin (tons/day)	Acidity Discharged to Streams - 1966 (tons/day)	Miles of Polluted Streams			Unre Surf (ac)
				Inter-mittently	Continu-ously	Total	
Anthracite Region (Susquehanna & Delaware)	4,200	2,300	350	350	260	610	
Tioga	2,800	10	8	20	35	55	
West Branch Susquehanna	6,900	700	250	600	540	1,140	
Juniata	3,400	60	19	20	60	80	
North Branch Potomac	2,200	70	33	40	130	170	
Allegheny	11,730	2,400	1,600	87	979	1,066	
Monongahela	7,400	3,000	1,200	289	1,382	1,671	
Beaver	1,500	> 165	50	40	68	108	
Muskingum	4,340	500	400	108	414	522	
Hocking	1,200	335	200	141	223	364	
Little Kanawha	2,300	> 10	10	25	5	30	
Kanawha	12,300	550	350	544	859	1,403	
Scioto	2,300	10	5	8	0	8	
Guyandotte	1,670	200	100	11	288	299	
Big Sandy	4,300	620	300	442	58	500	
Ohio & Minor Tributaries	12,600	> 1,000	1,000	166	1,164	1,330	
Kentucky	4,500	> 155	> 100	430	65	495	
Cumberland	10,850	> 200	> 200	305	205	510	
Tennessee - Black Warrior	28,000	> 20	> 20	--	--	155	
		> 12,305	> 6,195	3,656	6,705	10,516	

^{1/} From U. S. Geological Survey Prof. Paper 580, Mineral Resources of the Appalachian Region.

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of Data Concerning Mine Drainage
on in Appalachia

Miles of Polluted Streams			Unreclaimed Surface Mined Lands (acres)	Area Underlain by Coal Reserves (square miles)	Recoverable Coal (millions of tons)
Inter- mittently	Continu- ously	Total			
350	260	610	84,200	489	1,600
20	35	55	4,000	59	17
600	540	1,140	71,300	3,606	2,126
20	60	80	20,400	81	95
40	130	170	5,000	720	--
87	979	1,066	79,000	6,700	11,000
289	1,382	1,671	79,000	5,500	23,000
40	68	108	20,000	1,120	3,000
108	414	522	29,000	3,580	8,000
141	223	364	4,000	1,000	> 1,000
25	5	30	4,000	1,400	2,000
544	859	1,403	64,000	8,600	23,000
8	0	8	1,000	350	150
11	288	299	11,000	1,600	5,000
442	58	500	31,000	4,300	11,000
166	1,164	1,330	48,000	9,400	--
430	65	495	10,000	3,000	--
305	205	510	29,000	7,500	--
--	--	155	18,600	--	--
3,656	6,705	10,516	613,500		156,608 ^{1/2}

Appalachian Region.

Table 1-A

Coal Mine Drainage Sources Invent
by FWPCA in Appalachia - March 1

Sub-area	Active Operations						No. of Sources		
	Underground Mines		Surface Mines		Combination Surface & Underground Mines			Other Sources ^{1/}	
	No. of Sources	Net Acidity (lbs./day)	No. of Sources	Net Acidity (lbs./day)	No. of Sources	Net Acidity (lbs./day)		No. of Sources	Net Acidity (lbs./day)
Anthracite Area									
Susquehanna Basin	36	127,200	-	-	-	-	-	-	
Delaware Basin	4	2,800	-	-	-	-	-	-	
Tioga River	-	-	-	-	-	-	-	-	
West Branch Susquehanna	19	12,800	17	2,500	-	-	-	-	
Juniata River	-	-	-	-	-	-	-	-	
Allegheny River									
Clarion River	4	130	3	1,281	1	324	1	60	
Kiskiminetas River	31	145,986	5	508	-	-	1	84	
Monongahela River	175	325,494	49	24,007	23	60,288	23	5,877	1
Ohio River Tributaries									
Wheeling Cr.	2	137	-	-	-	-	-	-	
Raccoon Cr.	-	-	1	84	-	-	1	869	
Captina Cr.	7	346	-	-	-	-	2	6,371	
Total Sources Inventoried	278	614,201	75	28,380	24	60,612	28	13,261	2

^{1/} Other active sources are coal processing plants and refuse disposal areas associated with active mines

^{2/} Other inactive sources are abandoned refuse piles and seepages that can not be identified with specific

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Table 1-A

Coal Mine Drainage Sources Inventoried
by FWPCA in Appalachia - March 1969

			Inactive Operations							
on & nd	Other Sources ^{1/}		Underground Mines		Surface Mines		Combination Surface & Underground Mines		Other Sources ^{2/}	
Net idity (./day)	No. of Sources	Net Acidity (lbs./day)	No. of Sources	Net Acidity (lbs./day)	No. of Sources	Net Acidity (lbs./day)	No. of Sources	Net Acidity (lbs./day)	No. of Sources	Net Acidity (lbs./day)
-	-	-	73	387,400	3	900	-	-	1	100
-	-	-	41	25,300	3	300	-	-	-	-
-	-	-	15	21,700	7	2,400	-	-	-	-
-	-	-	560	266,600	267	104,600	-	-	104	112,500
-	-	-	44	37,900	-	-	-	-	-	-
324	1	60	145	33,180	240	92,643	57	18,786	40	7,099
-	1	84	381	423,945	155	13,223	107	26,089	84	102,358
,288	23	5,877	1,619	452,739	749	116,206	249	111,285	8	8,994
-	-	-	41	5,333	12	771	16	7,590	1	131
-	1	869	31	57,229	69	30,118	39	74,145	1	63
-	2	6,371	3	134	-	-	-	-	-	-
,612	28	13,261	2,953	1,711,460	1,505	361,161	468	237,895	239	231,145

Areas associated with active mines.

Areas not be identified with specific sources.

Table 1-A

Coal Mine Drainage Sources Inventoried
by FWPCA in Appalachia - March 1969
(Cont.)

Sub-area	Source Category Totals							
	Active Sources		Inactive Sources		Underground Sources		Surface Sources	
	No. of Sources	Net Acidity (lbs./day)	No. of Sources	Net Acidity (lbs./day)	No. of Sources	Net Acidity (lbs./day)	No. of Sources	Net Acidity (lbs./day)
Anthracite Area								
Susquehanna Basin	36	127,200	77	388,400	109	514,600	3	900
Delaware Basin	4	2,800	44	25,600	45	28,100	3	300
Tioga River	-	-	22	24,100	15	21,700	7	2,400
West Branch Susquehanna	36	15,300	931	483,700	579	279,400	284	107,100
Juniata River	-	-	44	37,900	44	37,900	-	-
Allegheny River								
Clarion River	9	1,795	482	151,708	149	33,310	243	93,924
Kiskiminetas River	37	146,578	727	565,615	412	569,931	160	13,731
Monongahela River	270	415,666	2,625	689,224	1,794	778,233	798	140,213
Ohio River Tributaries								
Wheeling Cr.	2	137	70	13,825	43	5,470	12	771
Raccoon Cr.	2	953	140	161,555	31	57,229	70	30,202
Capatina Cr.	9	6,025	3	134	10	212	-	-
Total Sources Inventoried	405	716,454	5,165	2,541,761	3,231	2,325,661	1,580	389,541

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Table 1-A

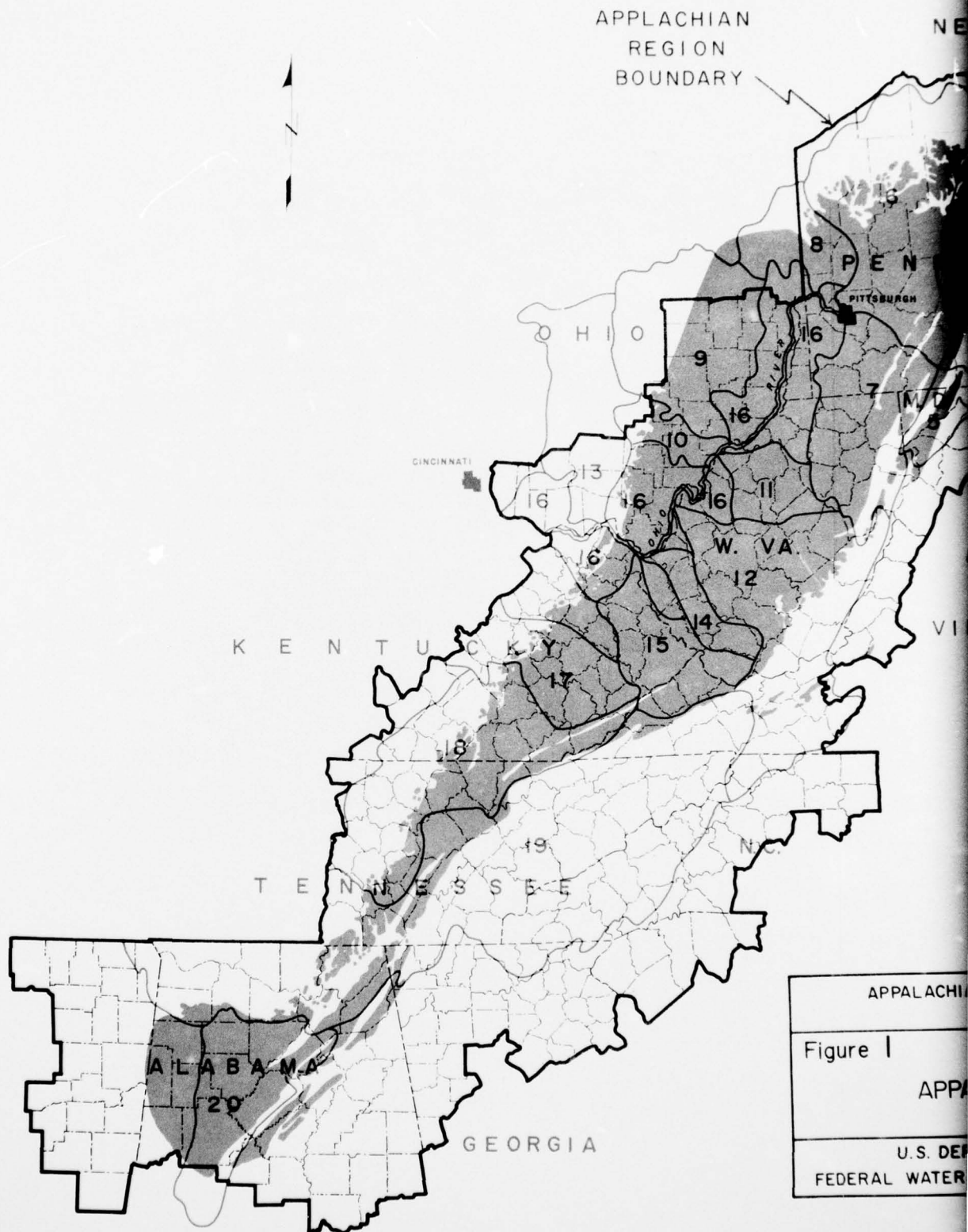
Mine Drainage Sources Inventoried
WPCA in Appalachia - March 1969
(Cont.)

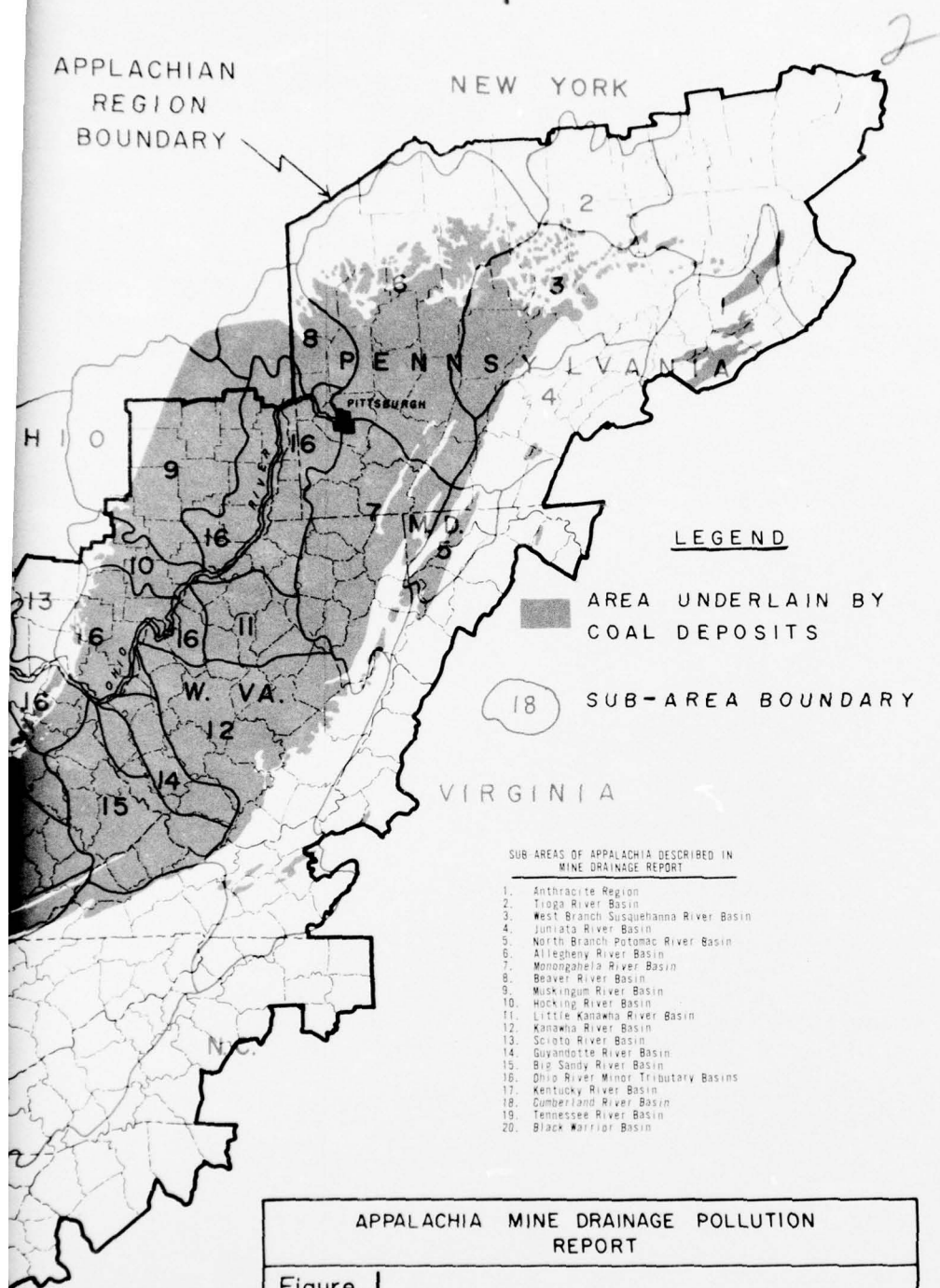
Source Category Totals									
Underground Sources		Surface Sources		Combination Sources		Other Sources		Total Sources	
No. of Sources	Net Acidity (lbs./day)	No. of Sources	Net Acidity (lbs./day)	No. of Sources	Net Acidity (lbs./day)	No. of Sources	Net Acidity (lbs./day)	No. of Sources	Net Acidity (lbs./day)
109	514,600	3	900	-	-	1	100	113	515,600
45	28,100	3	300	-	-	-	-	48	28,400
15	21,700	7	2,400	-	-	-	-	22	24,100
79	279,400	284	107,100	-	-	104	112,500	967	499,000
44	37,900	-	-	-	-	-	-	44	37,900
149	33,310	243	93,924	58	19,110	41	7,159	491	153,503
12	569,931	160	13,731	107	26,089	85	102,442	764	712,193
794	778,233	798	140,213	272	171,573	31	14,871	2,895	1,104,890
43	5,470	12	771	16	7,590	1	131	72	13,962
31	57,229	70	30,202	39	74,145	2	932	142	162,508
10	212	-	-	-	-	2	6,371	12	6,159
231	2,325,661	1,580	389,541	492	298,507	267	244,506	5,570	3,258,215

Table 1-B

Statistical Distribution by Number and Acid Contribution
of Mine Drainage Source Categories Shown in Table 1-A

Percent of Total Sources	Source Category				Total Percentages
	Underground Mines	Surface Mines	Combination Surface & Underground Mines	Other Sources	
Active Sources	5.0	1.4	0.4	0.5	7.3
Inactive Sources	<u>53.0</u>	<u>27.0</u>	<u>8.4</u>	<u>4.3</u>	<u>92.7</u>
Total	58.0	28.4	8.8	4.8	100.0
<hr/>					
Percent of Net Acidity					
Active Sources	18.8	0.9	1.9	0.4	22.0
Inactive Sources	<u>52.5</u>	<u>11.1</u>	<u>7.3</u>	<u>7.1</u>	<u>78.0</u>
Total	71.3	12.0	9.2	7.5	100.0





APPALACHIA MINE DRAINAGE POLLUTION
REPORT

Figure 1

APPALACHIA INDEX MAP

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

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SOURCES OF COAL MINE DRAINAGE POLLUTION

Several methods are presently used to recover coal; however, all the methods fall within the two general types of either surface or underground operations.

Surface, or strip mining, is practical in areas where the rock and soil overburden is relatively thin. The thickness of overburden for economical removal depends not only on the coal reserves but also upon the type of machinery that can be utilized. In selected areas, more than 100 feet of overburden rock have been stripped by means of large power shovels or other machinery. The first large strip trench that is formed is utilized for depositing the overburden from the adjacent trench. Consequently, in areas where the coal is relatively flat lying and the land surface is also of relatively low relief, strip mining disturbs large areas or blocks of land.

Where the coal crops out in a hill, the overburden thickens quickly and surface mining is limited to stripping of the coal outcrop around the hill. In order to remove additional coal from inside the hill, auger mining is commonly used after the final strip cut. Large augers, some of which are as much as seven feet in diameter, can mine several hundred additional feet into the hill.

In places where the overlying rock materials are thick, underground mining must be employed. Where the coal crops out at the land surface, a drift mine entry is constructed and mining is advanced into the coal bed. Where the coal bed is buried a considerable distance beneath the overlying rocks, a vertical shaft or a slope mine entry is constructed to the coal. Lateral entries are then driven into the coal bed.

All methods of surface and underground mining may result in some degree of mine drainage pollution. The quality and quantity of mine drainage pollutants produced from a mining operation depends upon such factors as:

- (1) The operating status of the mine (i.e., active or inactive).
- (2) Hydrologic, geologic, and topographic features of the surrounding terrain.
- (3) The type of mining method employed.
- (4) Availability of air, water, and iron sulfide minerals.

Drainage from a mining operation may be produced continuously or intermittently. Underground mines developed below the ground water table usually produce mine drainage continuously, the concentration of

pollutants varying as a function of the volume of water entering the mine, contact time, and available reactive materials. In cases where the ground water table is below the mining level during some seasons or when the mine receives direct surface water contributions, the discharge quality and quantity may vary greatly.

In surface mines, the discharge of the pollutants is often intermittent, generally occurring during and immediately after periods of precipitation. Runoff in stripped areas may find its way to a surface stream or be trapped in inadequately restored trenches or pits formed during the stripping operation. When the runoff is trapped, pools which may contain high concentrations of mine drainage pollutants are formed. During subsequent periods of high runoff, these pools may overflow, releasing concentrated "slugs" of mine drainage pollution to receiving streams. Although streams that are only intermittently polluted may be of good quality much of the time, the aquatic life community of streams receiving "slugs" of acid mine drainage may be damaged for extensive periods of time.

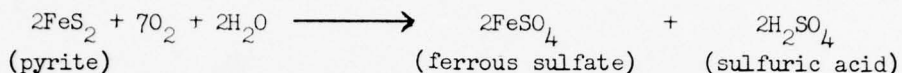
Between flush out periods, the pools in stripped areas often drain slowly into the backfill to emerge in the form of mine drainage seepages downslope from the stripping operation. They may also drain to underground mines underlying the stripped area, thus increasing the mine drainage flow from these mines. Mine drainage may continue to flow from inactive surface and underground mines as long as air, water, and sulfide minerals are available.

Disposal of the refuse materials from mines and coal preparation plants is one of the most difficult problems associated with active operations. Refuse piles are a major source of acid drainage in some areas and washery residue spillage is a frequent source of the fine coal and silt pollution common in some streams.

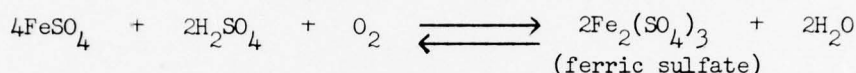
For field inventory purposes, a coal mine drainage source is considered to be a surface or underground location resulting from the handling or extraction of coal, containing minerals whose solution by contact water is resulting in a highly mineralized drainage. A drainage of greater than one gallon per minute is considered large enough to be included in a source inventory.

FORMATION OF POLLUTANTS IN COAL MINE DRAINAGE

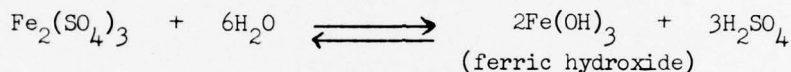
Although the exact reaction process is still not fully understood, the formation of acid mine drainage is generally illustrated by the equations shown below. The initial reaction that occurs when iron sulfide minerals are exposed to air and water produces ferrous sulfate and sulfuric acid.



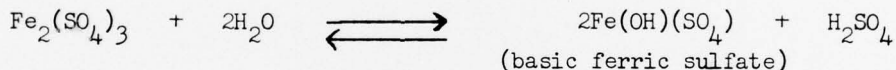
Subsequent oxidation of ferrous sulfate produces ferric sulfate.



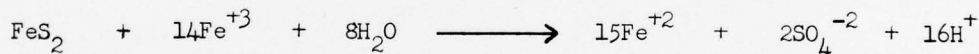
Depending on physical and chemical conditions, the reaction may then proceed to form ferric hydroxide or basic ferric sulfate.



and/or



Pyrite can also be oxidized by ferric iron as shown below.



Regardless of the reaction mechanism, the oxidation of one molecular weight of pyrite ultimately leads to the release of four molecular weights of sulfuric acid (acidity).

Other constituents found in mine drainage are produced by secondary reactions of sulfuric acid with minerals and organic compounds in the mine and along the stream valleys. Such secondary reactions produce concentrations of aluminum, manganese, calcium, sodium, and other constituents in the drainage water. These mine drainage constituents, along with iron and sulfate, are indicators of mine drainage pollution that may persist long after the acid in the drainage has been neutralized.

Although there are conflicting opinions among researchers as to the importance of micro-organisms in the productions of mine drainage pollution, there is evidence to indicate that micro-organisms do contribute to pyrite oxidation. A number of bacterial species including Thiobacillus thiooxidans, Thiobacillus ferrooxidans, and Ferrobacillus ferrooxidans have been isolated from mine drainage waters.

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WATER QUALITY EVALUATION

The intensity of coal mine drainage pollution is evaluated by measurement of various water quality parameters. The most common physical, chemical, and biological parameters used for evaluation are listed in Table 2.

Some of the chemical and physical parameters listed in Table 2 are incorporated in the water quality standards for interstate streams that have been promulgated under the Water Quality Act of 1965. The most commonly applied standard that reflects coal mine drainage pollution is pH. Pennsylvania's established standards call for a pH of not less than 6.0 or more than 8.5 for all perennial interstate streams, including those in the Susquehanna, Monongahela and Allegheny River drainages, which are the three major mine-drainage polluted drainages in Appalachia. West Virginia standards call for pH levels of not less than 6.0 or greater than 8.5, except for certain streams in the Monongahela River drainage, where a minimum pH of 5.5 has been established.

In addition to pH, Pennsylvania standards specify maximum total iron and average total dissolved solids levels of 1.5 mg/l and 500 mg/l, respectively, for most interstate streams affected by mine drainage. Maximum total manganese and maximum sulfate levels are also specified for some stream reaches.

Various analytical methods are available for measuring the physical and chemical parameters listed in Table 2. The current methods to be used within FWPCA and by other specified agencies are given in "FWPCA Official Interim Methods for Chemical Analysis of Surface Waters - September 1968" (Federal Water Pollution Control Administration, 1968).

Because the pollution of streams by coal mine drainage can be extremely damaging to aquatic life, biological observations and measurements are useful for evaluating the extent of pollution. Streams so polluted generally support only a few species of particularly tolerant plants and animals.

Damages to aquatic life from acid mine drainage are attributed usually to high concentrations of mineral acids, the ions of iron, sulfate, and the deposition of a smothering blanket of precipitated iron salts on the stream bed. In addition, zinc, copper, and aluminum have occurred at lethal concentrations in acid mine drainage; and arsenic and cadmium have been found at threshold concentrations. The toxicities of these elements are compounded by synergism among several of them: zinc with copper, zinc with cadmium, and copper with cadmium.

The toxicities of iron, copper, and zinc solutions are much greater in the acid waters polluted by coal mine drainage than in neutral or alkaline waters. Because of the complex chemical nature of coal mine drainage, it is impossible to assign its toxicity toward aquatic life to any single chemical constituent.

Toxic chemicals in acid mine drainage eliminate sensitive life forms; tolerant forms occasionally flourish to great numbers apparently unaffected by the pollutants. The specialized flora and fauna of acid mine drainage reflect harsh water quality conditions. Fish are usually not found when the pH of a stream is lower than 4.5. Conversely, populations of midge larvae (Tendipes sp.) may develop to nuisance proportions.

A qualitative biological examination of a stream heavily polluted by acid mine drainage (pH 4.0 or lower) may reveal a community structure similar to the following:

(1) Complex Plants

Cattails (Typha sp.) and some mosses; other vascular plant life is generally not found in acid mine drainage.

(2) Algae

Dense flowing mats of species of the green alga Ulothrix are so common as to attract the attention of casual observers; gelatinous mats of chlorophyll-containing flagellates (Euglena spp.) often color stream beds dark green; microscopic examination commonly reveals other species of green algae, including Microspora spp., Microthamnion sp., the flagellate Chlamydomonas sp., great numbers of diatoms Eunotia sp., Pinnularia sp., and Navicula sp., and lesser numbers of Surirella sp.

(3) Benthic Invertebrates

In severely polluted stream reaches, especially near the mine adits from which polluted water flows, no benthos will be found. In less severely polluted reaches, common inhabitants include midges (Tendipes spp. and others), alderflies (Sialis sp.), fishflies (Chaulioides sp.), crane-flies (Antocha sp. and others), dytiscid beetles, and caddisflies (Ptilostomis sp.). Swampy areas polluted by coal mine drainage contain the above forms, plus water boatmen, dragonflies, damselflies, and mosquitoes. Conspicuous by their absence are crayfish, blackflies, mayflies, stoneflies, and most species of caddisflies.

Table 2 - Physical, chemical, and biological criteria significant in evaluating mine drainage pollution of streams in Appalachia.

1	2	3	4	5
PARAMETER	RANGE OF VALUES OF CONCERN	MAJOR WATER USE(S) PROTECTED	SOURCE(S) OF CRITERIA	USUAL VALUES IN UNPOLLUTED WATERS IN APPALACHIA
1. pH	less than 6.0	uses involving aquatic life	1,2,3,4 (See listing below)	6.0 - 9.0
2. Acidity	sufficient to lower alkalinity below 20 mg/l	uses involving aquatic life	1	less than alkalinity
3. Alkalinity	< 20 mg/l	uses involving aquatic life	1	> 20 mg/l
4. Sulfates	> 250 mg/l	domestic and industrial water supply	1,2,3,4	< 20 mg/l
5. Hardness	> 250 mg/l	domestic and industrial water supply	1,2,3,4	< 150 mg/l
6. Total iron	> 1.0 mg/l	uses involving aquatic life, domestic and industrial water supply	5	< 0.3 mg/l
7. Manganese	> 1.0 mg/l	uses involving aquatic life, domestic and industrial water supply	2,4	< 0.05 mg/l
8. Aluminum	> 0.5 mg/l	uses involving aquatic life	1,4	absent
9. Suspended solids	> 250 mg/l	uses involving aquatic life	1	< 100 mg/l (except during high runoff periods)
10. Dissolved solids	> 500 mg/l	domestic and industrial water supply	1,2,3,4	< 250 mg/l
11. Complex plants	Vascular plants community restricted; limited to <i>Typha</i> sp.; mosses present.	uses involving aquatic life	6	great variety of plant life
12. Simple plants	Algal community restricted; dominated by one to eight species, especially <i>Ulothrix</i> , <i>Euglena</i> , and pennate diatoms.	uses involving aquatic life	6,7	great variety of algae
13. Benthos	Lacking in mayflies, stoneflies, most caddisfly species, crayfish and blackflies. <i>Tendipes</i> or <i>Sialis</i> may be very abundant.	uses involving aquatic life	6	great variety of benthos
14. Fishes	Lacking or much restricted.	fishing	6,8	varied fish fauna

List of sources in Table 2, complete references listed in pages 268 to 271.

- | | |
|---|---------------------------|
| 1. U. S. Dept. of the Interior, 1967. | 5. Ellis, 1937. |
| 2. Pennsylvania Sanitary Water Board, 1967. | 6. Lackey, 1938 and 1939. |
| 3. U. S. Dept. of Health, Education and Welfare, Public Health Service, 1962. | 7. Joseph, 1953. |
| 4. McKee and Wolf, 1963. | 8. Parsons, 1957. |

(4) Fish: Absent

Upstream reaches, not polluted by acid mine drainage, might support several species of rooted and floating vascular plants, twenty or thirty species of algae, fifteen or twenty species of benthic invertebrates, and a mixed community of fishes. Severely polluted stream reaches might support only three or four species of algae; in less severely polluted reaches, only one or two species of vascular plants, three or four species of algae, three or four species of benthic invertebrates, and no fish.

Sampling Methods Include:

(1) Periphyton

Qualitative samples may be scraped from the stream bed or from any submersed object. Preferably, unpreserved samples should be examined; if live examination is impracticable, samples may be preserved in 5% formalin, 70% isopropyl alcohol, Lugol's iodine solution, or King's fluid (Joseph, 1953). Quantitative samples have been collected by the Acid Mine Pollution Control Demonstration Program by submerging glass microscopic slides secured to clay bricks with adhesive putty. Preservation or quantitative samples is by the same methods as listed above.

(2) Algae

Collection by routine water samples collected 1-foot beneath surface; preservation and examination techniques as discussed in Standard Methods (American Public Health Association and others, 1965, p. 644).

(3) Benthos

Qualitative samples may be taken by screening river bed materials, examining rocks, and other submerged objects. Quantitative samples may be taken by Petersen dredge or Surber square foot sampler. In using artificial substrata, inert materials should be used, because most metals are quickly corroded by acid mine drainage. Benthic invertebrates may be preserved in 10% formalin.

(4) Fish

It is recommended that all polluted streams be examined for the presence of fish. Standard collection methods, such as poisoning, netting, and electroshocking may be used.

DAMAGES

Discharge of acid coal mine drainage to surface waters changes the water quality by:

- (1) Lowering the pH
- (2) Reducing the natural alkalinity
- (3) Increasing the total hardness
- (4) Adding undesirable amounts of iron, manganese, aluminum, sulfates, and other elements and suspended material.

Some tangible damages resulting from these quality changes that can be evaluated in monetary terms are:

- (1) The cost to municipal and industrial water treatment plants for the required additional treatment of polluted water and early replacement of equipment damaged by polluted water.
- (2) The cost of early replacement of steel or iron structures and equipment such as culverts, bridges, locks, boat hulls, steel barges, pumps and condensers. Concrete structures may also be damaged.

Damages to recreational uses and aesthetic values are difficult to measure in economic terms, but are important. Such damages are:

- (1) Streams may be rendered less desirable or unusable for water-related recreational uses such as fishing, boating, water skiing, swimming, camping, and picnicking.
- (2) The elimination or alteration of biological life.
- (3) The lowering of property values along polluted streams.

The details of the damages to some specific water uses are;

Water Supplies

Adverse effects to water supplies are caused by the increased concentrations of acidity, iron, manganese, hardness, color, silt, coal fines, and sulfates that may result from coal mining and/or coal processing operations.

High acidity and low pH increase corrosivity and may interfere with water treatment processes such as coagulation and softening. Iron and manganese in concentrations above 0.3 mg/l and 0.05 mg/l, respectively, cause aesthetic problems such as staining of laundry and undesirable tastes. Hardness causes excess soap consumption and boiler scaling. These undesirable characteristics can be eliminated by treatment of the polluted water but water treatment costs are thereby increased.

Recreation

The discharge of mine drainage and coal mining or coal processing wastes into streams and lakes impairs their quality for fishing and makes them unattractive for boating, water skiing, swimming, and even picnicking. The destruction of aquatic life by mine drainage results from the toxicity of chemicals in mine drainage and from the blanketing action of iron precipitates and other suspended materials. Acid mine waters are harmful to most aquatic organisms. Fish are not only killed directly by mine drainage, but are also unable to survive because of the destruction of important food elements. The specialized flora and fauna that develop in mine drainage polluted waters may produce nuisance conditions such as large hatches of midges.

PRESENT CONDITIONS

Methods of Study

The extent of stream pollution by coal mine drainage in Appalachia has been determined and an initial inventory of the sources of drainage pollution has been made in a substantial proportion of the region. The studies leading to the accumulation of these data have been carried out by personnel in the Ohio Basin, Middle Atlantic and Southeast Regions of FWPCA in cooperation with the States and other Federal agencies.

For the most part, this study was coordinated with continuing FWPCA programs in mine drainage pollution control and for reasons such as local magnitude of the problem, geography, and available regional resources, some areas of the Appalachian Region are more completely described than others.

Description of mine drainage pollution in the Appalachian Region is given by sub-areas, which are discrete drainage basins with the exception of the Anthracite area that includes portions of the Susquehanna and Delaware watersheds. The sub-areas are described in a geographic sequence, the 5 areas in the Delaware, Susquehanna, and Potomac River basins are described first, followed by the 14 sub-areas of the Ohio River basin and an area in the Black Warrior River drainage, Alabama. Discussion of the Black Warrior basin is combined with that of the Tennessee basin because of the close geographic relation of the two basins and the similarity of the pollution problems in the two areas.

Generally, the determination of those streams significantly polluted by mine drainage was first made by consulting with other Federal and State agencies, by review of published and unpublished reports, and in some cases by field reconnaissance. On the basis of this initial work, stream sampling stations were established on many of the streams. From one to eight samples were taken at each location, most of them during the summer months of 1966, and appropriate chemical analyses were made. Water quality data were examined with regard to their compliance with water quality criteria and standards in making final determinations of the extent of stream pollution from mine drainage.

Acidity loadings are frequently given within this report as net acidity. Net acidity is the measured acidity less the measured alkalinity. Net acidity and measured acidity loadings are the same at pH values below 4.5, since there is no alkalinity to be subtracted. In samples with a pH above 4.5, reporting of net acidity loadings gives a more conservative appraisal of stream conditions than does reporting of total measured acidity loadings.

Streams are shown in the sub-area maps as being continuously affected by mine drainage or intermittently or potentially affected. Continuously affected streams are those that have been observed to be significantly degraded all or nearly all of the time. Intermittently or potentially affected streams are those that have been observed to be significantly degraded from time to time or where the potential exists and intermittent pollution probably occurs. Almost all of the streams in northern Appalachia that are classed as intermittently or potentially affected are known to be significantly affected. The potentially affected streams are almost entirely in Kentucky, Tennessee, and Alabama.

Field crews have located, sampled, and described point sources of mine drainage in the Susquehanna, Monongahela, and most of the Allegheny basins and in portions of some other sub-areas. Field work in the Allegheny River basin has been done cooperatively with the State of Pennsylvania. This work has usually involved only one visit to a drainage source and the flows and quality measurements that have been made are generally representative of dry summer conditions. For this reason, the amount of acid drainage observed to originate from the individual sources totals much less than the year-around average amount carried by streams in a drainage basin.

Throughout the report, the sulfate ion concentration and sulfate ion loading in the Region's streams has been used as an indicator of the amount of acid formed in sub-areas of the Region. This procedure has been used because one molecular weight of sulfate is formed for each molecular weight of acid that results from pyrite oxidation. In addition, sulfate ion is present in relatively low concentrations in unpolluted streams, it is a persistent element, and the analysis for sulfate is relatively reliable.

SUB-AREA DISCUSSIONS

Anthracite Area

Description

Anthracite coal deposits in the study area lie in four individual fields in northeastern Pennsylvania (Figure 2). The coal fields, underlie a total area of 484 square miles, and are designated the Northern field, Western Middle field, Eastern Middle field, and Southern field. The area includes portions of Carbon, Columbia, Dauphin, Lackawanna, Lebanon, Luzerne, Northumberland, Schuylkill, Susquehanna, and Wayne Counties.

All of the Northern field lies within the Susquehanna River basin. Approximately 50 percent of the Eastern Middle field, 90 percent of the Western Middle field, and 40 percent of the Southern field are drained by the Susquehanna River and its tributaries. The remainder of the fields drain to the Delaware River through its tributaries, the Lehigh and Schuylkill Rivers.

Major streams draining the Anthracite area are as follows:

<u>Name</u>	<u>Drainage Area (square miles)</u>	<u>Mile Pt. of Confluence</u>
Susquehanna River Basin		
Lackawanna River	346	195
Nescopeck Creek	172	159
Catawissa Creek	155	143
Shamokin Creek	138	122
Mahanoy Creek	155	112
Mahantango Creek	164	102
Wiconisco Creek	116	96
Swatara Creek	567	60
Delaware River Basin		
Lehigh River	1,373	
Schuylkill River	1,916	

The Anthracite area lies entirely within the Valley and Ridge Province of the Appalachian Highlands, the principal feature of which is a series of canoe shaped valleys in which the coal deposits are located. The ridges trend generally northeast to southwest with elevations varying from 1,400 to 2,700 feet.

All the rocks of the area are of sedimentary origin and range in age from Pennsylvanian to Silurian. The Pennsylvanian age Llewellyn formation contains the most economically important deposits of Pennsylvania anthracite coal, with the underlying Pottsville Formation containing the remaining reserves. These formations consists of alternating beds of sandstone, shale, fireclay, black carbonaceous slate, and coal. The Llewellyn and Pottsville formations contain from 12 to 26 minable coal beds. Coal beds range from several inches to many feet thick. The Great Mammoth bed has a thickness, in areas, in excess of 60 feet.

In the Northern field, coal deposits are contained within a canoe-shaped syncline which has a flat bottom and steep sides that outcrop along the mountain ridges. The field is about 62 miles long, 5 miles wide and covers an area of approximately 176 square miles. The Northern field is separated into two coal basins, the Lackawanna and Wyoming, near Old Forge, Pennsylvania, by a geological structure.

The Eastern Middle field, encompasses an area of approximately 33 square miles and consists of a number of long, narrow coal basins trending east to west. Most of the coal seams lie above surface drainage level and are drained by tunnels driven expressly to provide gravity drainage to surface streams. Numerous mine openings, slopes, drifts, and short tunnels also provide drainage.

The Western Middle field consists of a series of parallel, irregularly shaped coal basins covering an area of approximately 120 square miles. The field, about 42 miles long and from two to five miles wide, contains strata that locally may lie nearly horizontal or dip steeply. Deposits resemble those in the Eastern Middle field, except that most of the deposits lie below surface drainage level and are now flooded.

The Southern field, about 70 miles long and 1 to 6 miles wide, covers an area of about 200 square miles. The geologic structure of the Southern field is more complicated than that of the other fields. The coal beds dip more steeply than elsewhere and are more complexly faulted. The largest tonnage of anthracite reserve lies in this field.

Approximately 95 percent of the Nation's **true anthracite** lies in Pennsylvania in the watersheds of the Susquehanna and Delaware Rivers. Since 1808, over five billion tons of anthracite has been mined. Remaining anthracite coal reserves within the Susquehanna River basin have been estimated at 22.6 billion short tons. Recoverable reserves are estimated to be 11.6 billion tons (U.S. Geol. Survey, 1968).

Peak production was slightly more than 100 million tons per year. Production decreased gradually to a low of about 16.5 million tons in 1964. Projected estimates of anthracite production for the area are as follows:

Projected Anthracite Production (written communication U.S. Bureau of Mines)

	<u>1970</u>	<u>1985</u>	<u>2020</u>
Susquehanna Basin	5,900	3,200	2,500 thousand tons
Delaware Basin	5,300	4,200	9,500

Mine Drainage Sources and Their Effect on Stream Quality

There are presently about 160 significant mine drainage sources (active and inactive) and 84,200 acres of unreclaimed surface-mined land in the Anthracite area. The drainage from these underground and surface sources is causing continuous significant degradation of 260 miles of streams and intermittent significant pollution of 250 miles of streams.

The distribution of and pollution loads contributed by major mine drainage discharge sources within the Anthracite area are shown on the following page.

Figures 3, 4 and 5 show that for the years for which data are available the average total sulfate loadings were about 190 tons/day in the Lehigh River at Catasqua, 425 tons/day in the Schuylkill River at Berne, and 2,000 tons/day in the Susquehanna River at Danville. Of the total average sulfate loading of 2,615 tons/day at these three locations about 2,000 tons/day resulted from mine drainage originating in the Anthracite area. In addition, mine drainage sulfate loadings in Shamokin Creek, Manahoy Creek, and Swatara Creek total about 300 tons/day, bringing the total sulfate loadings resulting from mine drainage in the Anthracite area to 2,300 tons/day. This figure can be considered to indicate the average daily quantity of mine drainage acidity formed in the Anthracite area during the years for which data are available. Field measurements of active drainages indicate that of the 2,300 tons/day of acidity formed in the area about 350 tons/day enters streams unneutralized. The amount of mine drainage indicators entering streams in the Anthracite area each year can be considerably greater or lesser than the average amount depending on mining activity, amount of rainfall, and other related factors.

A detailed discussion of the mine drainage sources in the Anthracite area, and their effect on stream quality follows:

Mine Drainage Sources and Net
Acidity Contributions
Anthracite Area

Area	Sub-Area	Active Operations				Inactive Operations				Total Sources			
		Underground Mines		No. of Sources	Underground Mines		Surface Mines		Other Sources ^{1/}		No. of Sources	Net Acidity	
		No. of Sources	Net Acidity ^{2/}		No. of Sources	Net Acidity	No. of Sources	Net Acidity	No. of Sources	Net Acidity			
Anthracite Area													
	Lackawanna River			13	83,000					13	83,000		
	Wyoming Valley	2	86,000	3	142,000					5	228,000		
	Nescopeck Creek			4	64,800					4	64,800		
	Catawissa Creek			6	27,800					6	27,800		
	Shamokin Creek	2	6,600	6	27,400	1	200			9	34,200		
	Mahanoy Creek	5	28,900	13	28,900					18	57,800		
	Mahantango Creek	22	2,900	10	2,200					32	5,100		
	Wiconisco Creek			5	3,600					5	3,600		
	Swatara Creek	5	2,800	13	7,700	2	700	1	100	21	11,300		
	Lehigh River			8	9,000	3	300			11	9,300		
	Schuylkill River	4	2,800	33	16,300					37	19,100		
	(Sub-Total)	40	130,000	114	412,700	6	1,200	1	100	161	544,000		

^{1/} Other inactive sources are abandoned refuse piles and seepages that can not be identified with specific sources.

^{2/} Net acidity in pounds per day.

A. Lackawanna River

Changes in mining activity and mine drainage discharge points have greatly altered the quality of the Lackawanna River within the past 10 years. Prior to 1960, extensive mining with associated mine drainage severely degraded stream quality. Declines in demand for anthracite coal, the cost of pumping high volumes of water, and other circumstances gradually forced the abandonment of most of the deep mines and inactive mines account for virtually all drainage pollution in the area.

Cessation of mining and mine water pumping has resulted in a very significant increase in stream alkalinity although some mine drainage influence on stream quality persists. In January 1961, the mine water pools which had been developing in the abandoned underground workings broke through the surface in the form of a gravity discharge to the Lackawanna River at Duryea, approximately two miles from its mouth. The largest discharge of mine drainage in the Anthracite field is a combination of the Duryea gravity discharge and the discharge from a borehole, which was subsequently drilled one mile upstream at Old Forge in order to stabilize the level of the underground pools. The combined discharges contribute an average flow of about 58 mgd, an acid load of approximately 66 tons/day net acidity, and an iron load of approximately 31 tons/day.

Although most of the mine water in the Lackawanna River watershed discharges to the river through the Duryea and Old Forge discharge points, as illustrated in Figure 6, water quality in the river is also influenced by other mine drainage discharges.

The initial effect of mine drainage on stream quality is evident immediately above Carbondale and downstream from Elk Creek. Based on an acidity-alkalinity balance, this reach of the Lackawanna River receives a net acid loading of at least 0.5 tons/day from the combined flows described above. Between Carbondale and Old Forge, the river receives mine drainage contributed primarily by the Jermyrn Water Tunnel, which contributes approximately 2.7 tons/day net acidity.

Between the entry of the Jerwyn discharge and the confluence with the Susquehanna River, the Lackawanna River receives the Duryea and Old Forge discharges. These discharges overcome the stream's residual alkalinity and were primarily responsible for the acid loading of 23.5 tons/day net acidity discharged at the mouth of the Lackawanna River during the sampling period. The Lackawanna River discharge does not deplete the Susquehanna River's alkalinity reserve. However, iron and manganese loadings originating in the Duryea and Old Forge discharges are responsible for substantial degradation of the quality of the Susquehanna River.

Variation of mine drainage indicators throughout the length of the Lackawanna River is illustrated in Figures 6 and 7. At its mouth the pH is generally between 4 and 6. The acidity concentration is about 150 mg/l and iron and manganese concentrations are normally in the 50 mg/l and 10 mg/l range, respectively.

B. Susquehanna River-Lackawanna River to Nescopeck Creek

The quality of the Susquehanna River is impaired in this reach by mine drainage contributed by the Lackawanna River and prior to November 1967 by discharges originating in the Wyoming Valley portion of the Northern Anthracite field. Tributary streams contributing most of the mine drainage originating in the Wyoming Valley included: Mill Creek, Solomons Creek, Warrior Run, Nanticoke Creek, and Newport Creek (Figures 8 and 9). These streams conveyed discharges from large mine-pumping stations and the water quality of the streams approximated the qualities of the discharges.

All of the pumping operations that contributed a significant amount of acid to the Susquehanna River were operated by the Blue Coal Company. The company operated a total of 27 pumps and 17 locations. The total flow of pumped discharges averaged 62 mgd the acid loading averages 180 tons/day net acidity and the iron loading averages 67 tons/day.

Under the direction of the Pennsylvania Sanitary Water Board, the Blue Coal Company regulated its discharges in accordance with streamflow, pumping only as necessary to prevent flooding of the active mines during low streamflow periods. Calculations based on pumping records and discharge and stream quality records indicate the following contributions from major sources during the period of sampling in the area -- August 1965:

- a. Mill Creek - 42.5 tons/day net acidity from the Delaware pumps.
- b. Solomons Creek - 13.5 tons/day net acidity from Huber (7.5 tons/day) and the treated South Wilkes-Barre #5 discharge (6 tons/day). The latter discharge is permitted only with treatment during low flow periods and was active only during the period August 19-31.
- c. Warrior Run - 2 tons/day net acidity originating in discharges from Sugar Notch West (0.5) and Sugar Notch shaft (1.5 tons/day).
- d. Nanticoke Creek - 12 tons/day from the Askam pumped discharge. The Loomis outfall, permitted with treatment during the low flow period, was operated only 53 hours during the month and is not considered here.

- e. Newport Creek - 43 tons/day net acidity and 9 tons/day total iron from the Wanamie mining complex.

Although the Susquehanna River received sizable acid contributions from the pumped discharges during the survey period, its alkaline reserve was not seriously threatened. Other mine drainage indicators, particularly manganese and sulfates, were, however, present in relatively high concentrations.

Samples collected in August 1966 at mile 196 upstream from the Lackawanna River and at mile 179 downstream from all significant Northern Anthracite field mine drainage sources indicate reduction in alkalinity and increases in other mine drainage indicators through the reach. Alkalinity dropped from about 84 mg/l to 38 mg/l. Iron, manganese, and sulfate increased from 0.1, 0.09, and 30 mg/l to about 0.3, 1.5, and 190 mg/l, respectively. During the sampling period iron concentrations in this reach were abnormally low. Other data available indicate that the change in concentrations of iron and other mine drainage indicators through the reach is considerably more dramatic under other flow conditions.

In October 1967, the high cost of pumping water and other factors combined to force the Blue Coal Company to discontinue mining operations in areas that required extensive pumping. Essentially all of the pumping was discontinued. It was originally estimated that mine water pools would fill and overflow in two years, but very rapid filling required that the Pennsylvania Department of Mines and Mineral Industries begin pumping in 1968 to prevent flooding and surface subsidence. Pumping is presently from the Delaware Pool. It is planned that, in the future, pumping will be from two locations.

C. Susquehanna River - Nescopeck Creek and Below

Downstream from Nescopeck Creek, stream quality rapidly improves. Downstream tributaries draining the Anthracite area contribute mine drainage, but do not significantly affect stream quality. Biological surveys disclosed significant degradation of aquatic life in the reach from the Lackawanna River to Nescopeck Creek and slight effect further downstream. Periodic degradation of stream quality downstream from Nescopeck Creek has been observed during periods of high streamflow following extended low flow periods. Iron salts that precipitate upstream from Berwick during low flow periods are scoured out during high flows and are evident downstream to the confluence with the West Branch Susquehanna River.

1. Nescopeck Creek

The quality of the upper reaches of Nescopeck Creek above its confluence with Little Nescopeck Creek is not significantly degraded by mine drainage. In fact, this 10-mile reach is classified as a trout stream by the Pennsylvania Fish Commission. Below the confluence, however, stream quality is degraded by mine drainage from Little Nescopeck Creek and Black Creek.

The contribution of approximately 3.5 tons/day net acidity by Little Nescopeck Creek overcomes Nescopeck Creek's natural alkaline reserve and renders it an acid stream. The mean acidity concentration in the Nescopeck Creek immediately downstream from the confluence with Little Nescopeck Creek was found to be 240 mg/l, the mean manganese concentration (8 mg/l) and the total iron concentration (6.5 mg/l). The prime source of pollution of Little Nescopeck Creek is the Jeddo Tunnel, which serves as a gravity discharge point for a large area of abandoned deep mine workings in Black Creek coal basin in the Western Middle anthracite field. The tunnel discharges an average of about 20 mgd with an acid loading of 49 tons/day net acidity.

The quality of Nescopeck Creek improves slightly from its confluence with Little Nescopeck Creek to its mouth. Within this reach, Black Creek contributes sizable loadings of mine drainage indicators, but concentrations of mine drainage indicators are less than those in Nescopeck Creek. The mixture of the two streams thus slightly improves the quality of Nescopeck Creek. Black Creek receives mine drainage discharges from the Gowan and Derringer drainage tunnels, the major mine drainage contributors in the watershed. In addition to mine drainage pollution, Little Nescopeck Creek and Black Creek receive coal silt from coal-processing operations and surface runoff from piles of coal fines.

2. Catawissa Creek

As a result of mine drainage contributions, Catawissa Creek is an acid stream throughout most of its length (Figures 10 and 11). Approximately 38 miles from its mouth, the stream, which at that point is normally alkaline although bearing evidence of mine drainage contributions, is diverted underground in an abandoned surface mining complex that has completely disrupted surface drainage patterns. The stream then apparently flows through abandoned deep mine workings for a distance of approximately 4,000 feet, emerging as the Green Mountain Water Level Tunnel discharge. The stream, bearing an acid load of about 150 tons/day net acidity, is further degraded about three miles

downstream by the contribution of a total of about 12 tons/day net acidity from two drainage tunnels, Audenreid and Green Mountain. The stream never recovers from this heavy acid loading.

Tomhicken Creek, with its contribution of 0.9 tons/day net acidity, constitutes the only other significant contributor of acid and other mine drainage indicators. Its contribution does not, however, significantly degrade the quality of Catawissa Creek, since pollutant concentrations are somewhat lower than those in the receiving stream. Most of the acid in Tomhicken Creek originates from the Cox #3 drainage tunnel, which contributed about 0.6 tons/day net acidity during the survey.

Although all of the known mine drainage discharges enter Catawissa Creek in the upper one-third of its length, the weak natural alkalinity and relatively small flow of downstream tributaries are not adequate to neutralize the heavy acid loadings that enter in the headwaters. Catawissa Creek contributes approximately 9.2 tons/day net acidity to the Susquehanna River. This loading is about 80 percent of the largest single contribution, the Audenreid Drainage Tunnel.

Unlike many of the streams in the Anthracite area, Catawissa Creek is not significantly influenced by coal silt, because there are no active coal processing operations in the drainage area.

3. Shamokin Creek

Shamokin Creek is an acid stream throughout 28 miles of its 35 mile length (Figures 12 and 13). The remaining seven miles, the extreme headwaters, although alkaline, were found to have high concentrations of mine drainage indicators, particularly iron and manganese. As shown in Figure 12, downstream from mile 29 the stream is rendered acid by mine drainage contributed by the North Branch Shamokin Creek and the Excelsior Drainage Tunnel. Although the acidity decreases fairly uniformly from about 200 mg/l at this point to about 100 mg/l at the mouth, the acid loading increases from about 4.5 tons/day net acidity to about 18.7 tons/day net acidity in the next 10 miles, then remains constant the remaining 18 miles to the mouth.

As shown in Figure 13, the total iron concentration reaches a peak of 147 mg/l at mile 23 then declines to less than 20 mg/l at its mouth. Mean manganese concentrations range from 6 mg/l to 3 mg/l along the length of the stream. Sulfate concentrations range from 470 mg/l at mile 22 to 430 mg/l at the mouth.

In the Shamokin Creek watershed, all mine drainage discharges enter in the headwaters area, which is typical of the Anthracite fields. Seven major discharges were located in the upstream third of Shamokin Creek drainage. All but one of the discharges originate in underground mines, although they are undoubtedly influenced by surface water diverted underground in areas disturbed by surface mining. At the time of sampling, the seven major discharges contribute a flow of 13.1 mgd and 19 tons/day net acidity

Active underground mines contribute 19 percent of the net acidity load and inactive underground mines contribute 80 percent. The pumped discharge from the Glen Burn Colliery, along, contributes 15 percent.

In addition to constituents attributable to mine drainage, the stream is heavily laden with coal silt, much of which apparently originates at coal cleaning and processing operations.

4. Mahanoy Creek

Mahanoy Creek, although contributing a loading of approximately 0.5 tons/day net alkalinity to the Susquehanna River, is one of the most severely degraded streams draining the Anthracite area. The source of stream quality degradation is alkaline mine discharges that contain high concentrations of iron, manganese, and other mine drainage indicators. Severe degradation of stream quality was observed throughout the entire 52 mile length of Mahanoy Creek.

Major contributions of mine drainage reach Mahanoy Creek through the following tributaries: North Branch Mahanoy Creek, Waste House Run, Shenandoah Creek, Big Mine Run, and Zerbe Run. In addition, five large deep mine discharges enter Mahanoy Creek directly.

As shown in Figures 14 and 15, the stream's natural alkalinity is overcome in its upper reaches. This is primarily the result of an 0.4 tons/day net acidity contribution from the East Barrier gravity discharge, an intermittent pumped discharge from the Springdale Tunnel, and a 5.2 tons/day net acidity contribution by Waste House Run which originates in predominately pumped discharges.

Alkaline contributions by the Girardville No. 1 and No. 2 drainage tunnels and Big Mine Run overcome the acid residual and increase the stream's alkaline reserve to a peak of approximately 7.5 tons/day at a sampling station downstream from Big Mine Run. This reserve steadily decays to a minimum 0.5 tons/day at the mouth. The largest acid contribution in the portion of the basin downstream from Big Mine Run is Zerbe Run with its loading of 3.9 tons/day net acidity. Zerbe Run

receives essentially all of its acid loading from the Trevorton Tunnel discharge which contributed 6 tons/day net acidity during the survey period.

As illustrated in Figure 15, concentrations of mine drainage indicators vary greatly along the length of the stream. Mean manganese concentrations range from 2.7 mg/l to 20 mg/l; mean total iron concentrations range from 3 mg/l to 110 mg/l. Sulfate concentrations range from 1,050 mg/l to 1,500 mg/l throughout most of the length of the stream. Coal silt discolors the stream and practically fills the channel in some reaches.

5. Mahantango Creek

Mahantango Creek is an acid stream throughout approximately 17 miles of its 32 mile length and contributes approximately 1.8 tons/day net acidity to the Susquehanna River.

Essentially all of the mine drainage discharged in the Mahantango Creek basin comes to the surface in the watershed of Rausch Creek, a small (10 square mile drainage area) tributary to Pine Creek; which is in turn a tributary of Mahantango Creek.

Rausch Creek, with its acid loading of 2.5 tons/day net acidity, exhausts the alkaline reserve of Pine Creek at their confluence and renders it an acid stream for the remaining 13 miles of its length. The quality of Pine Creek is slightly improved by water contributed by alkaline tributaries, the largest of which is Deep Creek. Although influenced by mine drainage originating in the Hans Yost Creek watershed, Deep Creek is essentially neutral at its mouth.

As shown in Figure 16, the residual acid loading of about 1.5 tons/day net acidity which reaches Mahantango Creek easily overcomes its weak alkaline reserve and renders it an acid stream to its mouth. The portion of Mahantango Creek upstream from Pine Creek, although low in alkalinity, is of generally good quality. A biological reconnaissance in 1964 determined that this reach supported normal aquatic life.

Upstream from Pine Creek, Mahantango Creek is almost free of all mine drainage indicators and has, in fact, surprisingly low mineral content. For example, its mean sulfate concentration is 7 mg/l. Mean iron and manganese concentrations are 0.4 mg/l and 0.9 mg/l, respectively. Downstream from Pine Creek stream quality is relatively constant. Iron and manganese concentrations are slightly less than 0.6 mg/l. Mean net acidity ranges between 35 and 45 mg/l (see Figure 17).

Mine drainage sources in the Mahantango Creek watershed, although clustered in a relatively small area of the Rausch Creek watershed, are not, as is the case in some of the watersheds already discussed, collected by drainage tunnels. Mine drainage is contributed to Rausch Creek through 22 known pumped discharges and 10 gravity discharges. The largest of the gravity discharges are the Markson and Valley View which are responsible for a total contribution of 0.8 tons/day net acidity.

6. Wiconisco Creek

Wiconisco Creek is an alkaline stream throughout its length and it contributes approximately 3 tons/day net alkalinity to the Susquehanna River. Its quality is degraded by coal silt, and mine drainage indicators for at least a portion of its length.

The major mine drainage sources are the Porter and Keefer drainage tunnels and Bear Creek, which receives mine drainage from two drainage tunnels. All of the major discharges are located in the upper one-third of the stream's length. Figure 18 illustrates the effect on stream alkalinity reserves of the contribution of 3 tons/day net alkalinity by Bear Creek, which neutralizes the .4 tons/day net acidity contributed by the Porter and Keefer Tunnels.

Although iron, manganese, and sulfate concentrations in Wiconisco Creek are temporarily elevated by contributions from Bear Creek, about 25 miles of stream downstream from Bear Creek are of relatively good chemical quality (see Figure 19). A summary of a biological survey of the stream conducted in 1964 reports essentially no aquatic life upstream from Bear Creek. Several species of clean water organisms were collected at the mouth, indicating at least partial recovery from the upstream pollution loadings. Coal silt loadings in the stream are heavy. These apparently originate in coal washeries in the basin.

7. Swatara Creek

Mine drainage renders Swatara Creek acid from its headwaters to its confluence with Mill Run, a distance of approximately 24 miles. Streams found to be contributing significant amounts of mine drainage to Swatara Creek during a survey of the basin in October and November 1965 were: Panther Creek, Good Spring Creek, and Lower Rausch Creek. As illustrated in Figure 20, Panther Creek, with its small contribution of net acidity does not significantly affect the alkalinity reserve of Swatara Creek. It does, however, contribute other mine drainage indicators. Figure 20 illustrates how the alkalinity reserve of Swatara Creek is affected by acidity from Good Spring Creek. Most of the mine drainage in the Good Spring Creek originates in the watershed of Middle Creek, a tributary

that enters Good Spring Creek about one mile from its mouth. Lower Rausch Creek contributes a net acid loading of 0.6 tons/day, most of which originates in three drainage tunnel discharges.

As shown in Figure 20, the acid loading in Swatara Creek reached a peak of 1.8 tons/day net acidity at mile 58, immediately downstream from Lower Rausch Creek, and then declined in response to the influence of alkaline tributary streams. As illustrated in Figure 21, stream quality in the headwaters reach fluctuates rather weakly in response to contributions by streams bearing mine drainage. Mean iron and manganese concentrations are about 3.5 mg/l. Sulfate concentrations are normally less than 250 mg/l. Downstream from mile 60, concentrations of all mine drainage indicators decline.

Considerable mining is presently being accomplished in the basin; however, most of the significant mine drainage discharges observed during the survey originate in abandoned mines. About 2.3 tons/day net acidity loading on the stream during the survey could be attributed to four deep mine discharges and the discharge of Middle Creek.

D. Schuylkill River

The Schuylkill River, a tributary of the Delaware River, drains a large portion of the Southern anthracite field. The Schuylkill River is rendered acid at its headwaters, apparently by runoff from refuse piles. Numerous discharges from all source categories add to the acid load upstream from the confluence with Mill Creek. Eleven major discharges to this reach contribute 1.1 tons/day net acidity.

Tributaries discharging significant amounts of mine drainage to the Schuylkill River include Mill Creek, West Branch Schuylkill River, and the Little Schuylkill River.

The Mill Creek receives drainage from four major discharges and contributes approximately 5.5 tons/day net acidity.

The next downstream source of acid is the West Branch Schuylkill River. The West Branch receives drainage from numerous mines of all categories and contributes approximately 2.3 tons/day net acidity. Most of the acid contributed by the West Branch may be attributed to one drainage tunnel which has an acid contribution of 3.4 tons/day.

The Little Schuylkill River is rendered acid at its source by several drainage tunnel discharges and receives additional acid from Wabash Creek (1 ton/day) and Panther Creek (3 tons/day). Although no samples are collected downstream from mine drainage sources, it is

believed that the quality of the Little Schuylkill River is degraded by mine drainage throughout its length. Nine major discharges contributing about 3 tons/day net acidity are located in this watershed. Drainage originates in both active and inactive mines. Acid contributed in the headwaters coupled with the acid contributed by Little Schuylkill River renders the Schuylkill River acid downstream to Reading.

Mine drainage discharges and the receiving streams in this sub-basin are generally low in iron and manganese concentrations. Net acidity and sulfate concentrations are relatively high. The quality of the Schuylkill River immediately downstream from the West Branch Schuylkill River is representative of the quality of most of its upstream tributaries. On the day of sampling the net acidity was 78 mg/l. Sulfate, iron, and manganese concentrations were 590, 2.5, and 7.8 mg/l, respectively.

Analysis of chemical data obtained by the U.S. Geological Survey at Berne, Pennsylvania, during 1948-1953 and 1957-1959 (Figure 4) shows that total sulfate loadings in the Schuylkill River averaged 425 tons/day. Of the total load, about 393 tons/day resulted from mine drainage, and this figure is considered to indicate the average amount of acidity formed daily in the Schuylkill basin during those years.

E. Lehigh River

Mine drainage contributed to the Lehigh River originates in the eastern edge of the Eastern Middle and Southern anthracite fields. Streams contributing significant amounts of mine drainage to the Lehigh River include: Sandy Run, Buck Mountain Creek, Black Creek, and Nesquehoning Creek. Essentially all the mine drainage in this basin originates in abandoned mines. Upstream from Sandy Run, the Lehigh River is almost neutral with a very low mineral content. Sandy Run with its acid load of 3 tons/day net acidity overcomes the weak natural alkalinity reserve and renders the Lehigh River acid. About 80 percent of the acid loading contributed by Sandy Run originates in the Owl Hole drainage tunnel discharge. Both Sandy Run and Pond Creek, its major tributary, are rendered acid from source to mouth by drainage from six major discharges, three of which are drainage tunnels.

Buck Mountain Creek contributed about 0.9 tons/day net acidity to the Lehigh River on the day of sampling. Essentially all of the acid originates in the discharges from two drainage tunnels, Buck Mountain No. 1 and Buck Mountain No. 2. The tunnels discharge to the extreme headwaters of Buck Mountain Creek and renders it acid throughout its length.

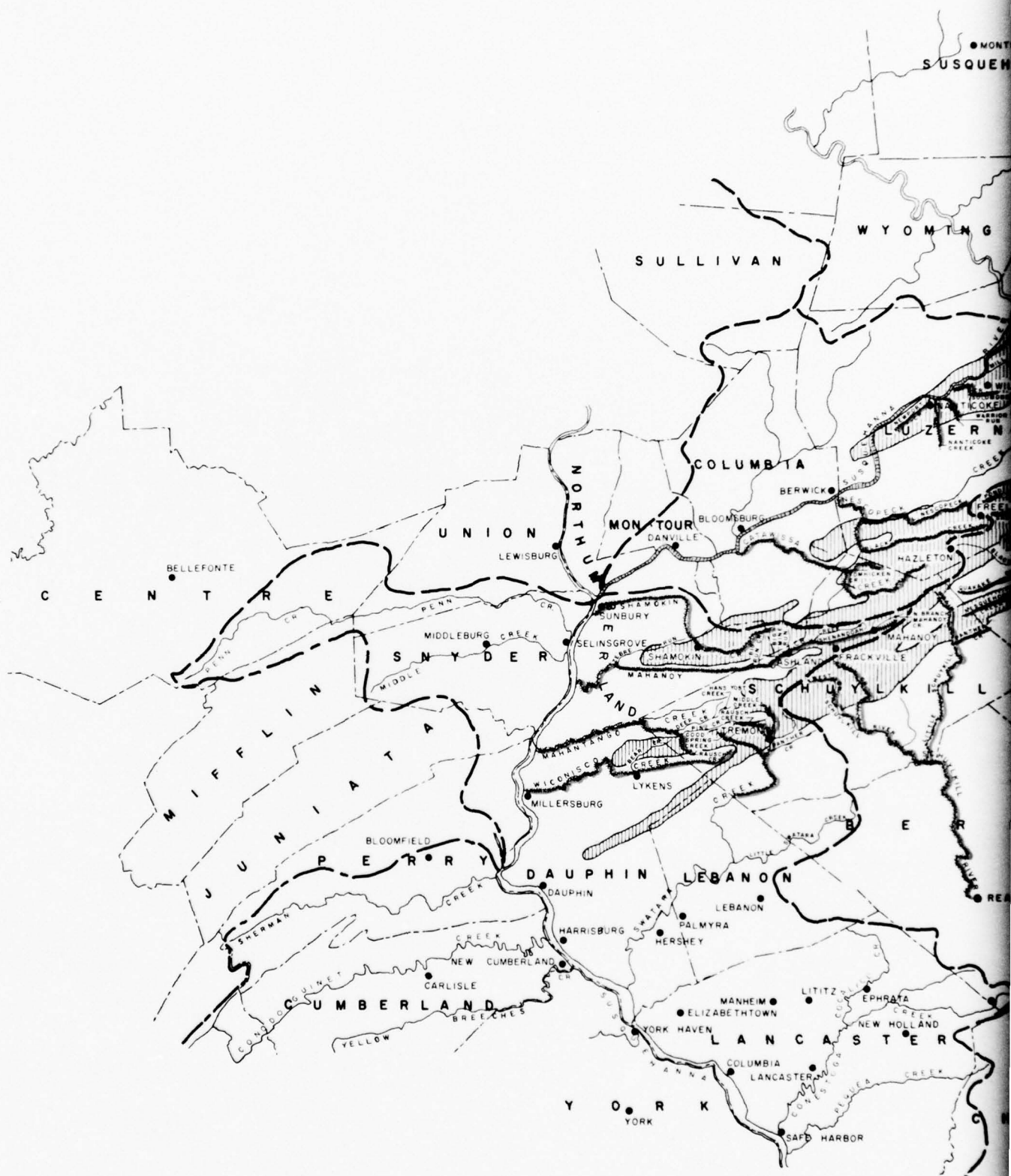
Black Creek contributes approximately 2.7 tons/day net acidity to the Lehigh River, all of which originates in one discharge, the Beaver Meadow (Quakake) Drainage Tunnel. The discharge constitutes

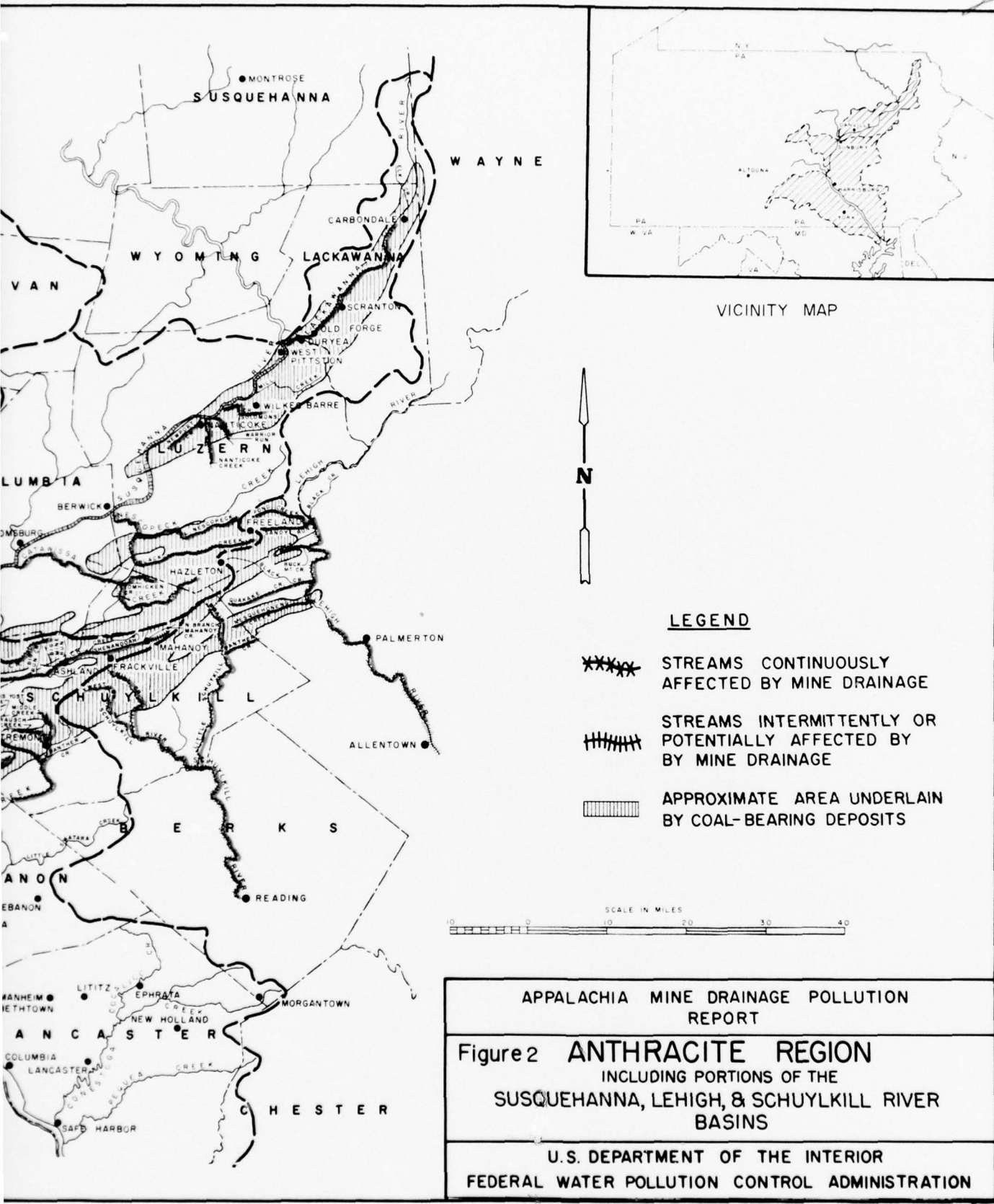
most of the flow of Quakake Creek, a tributary of Black Creek. Both streams are rendered acid by the discharge. Because of its large flow, Nesquehoning Creek, although only weakly acid at its mouth (13 mg/l on the day of sampling) contributes a sizable net acidity of 0.6 tons/day to the Lehigh River. The creek is acid throughout its length and receives most of its acid load from two drainage tunnels.

Although no samples were collected downstream from the acid tributaries, other available data indicate that the Lehigh River is severely degraded by the mine drainage downstream to Northampton.

The quality of mine drainage discharges in this basin is similar to that in the Schuylkill River watershed. The iron and manganese concentrations are relatively low, while acidity and sulfate concentrations are high.

Analysis of chemical data obtained by the U.S. Geological Survey at Catasaqua, Pennsylvania during 1945-1952 (Figure 3) shows that for those years the average daily sulfate loading was 190 tons/day. About 90 tons/day of sulfate is estimated to have resulted from mine drainage acidity, and this figure is considered to indicate the amount of acidity formed daily in the Lehigh basin at that time.





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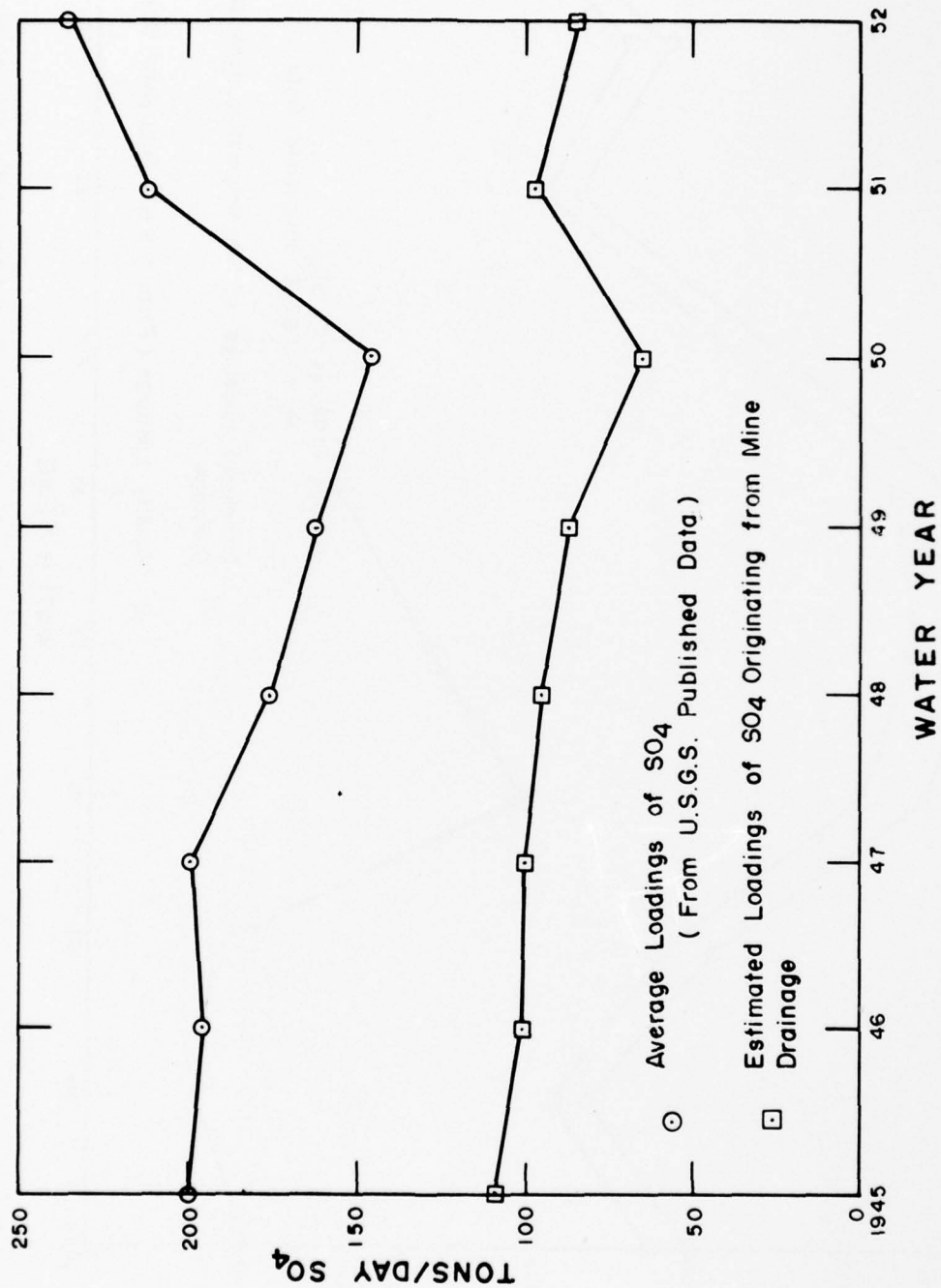


Figure 3. Average loads of total sulfate and sulfate considered to originate from coal mine drainage carried by the Lehigh River at Catsauqua, Pennsylvania.

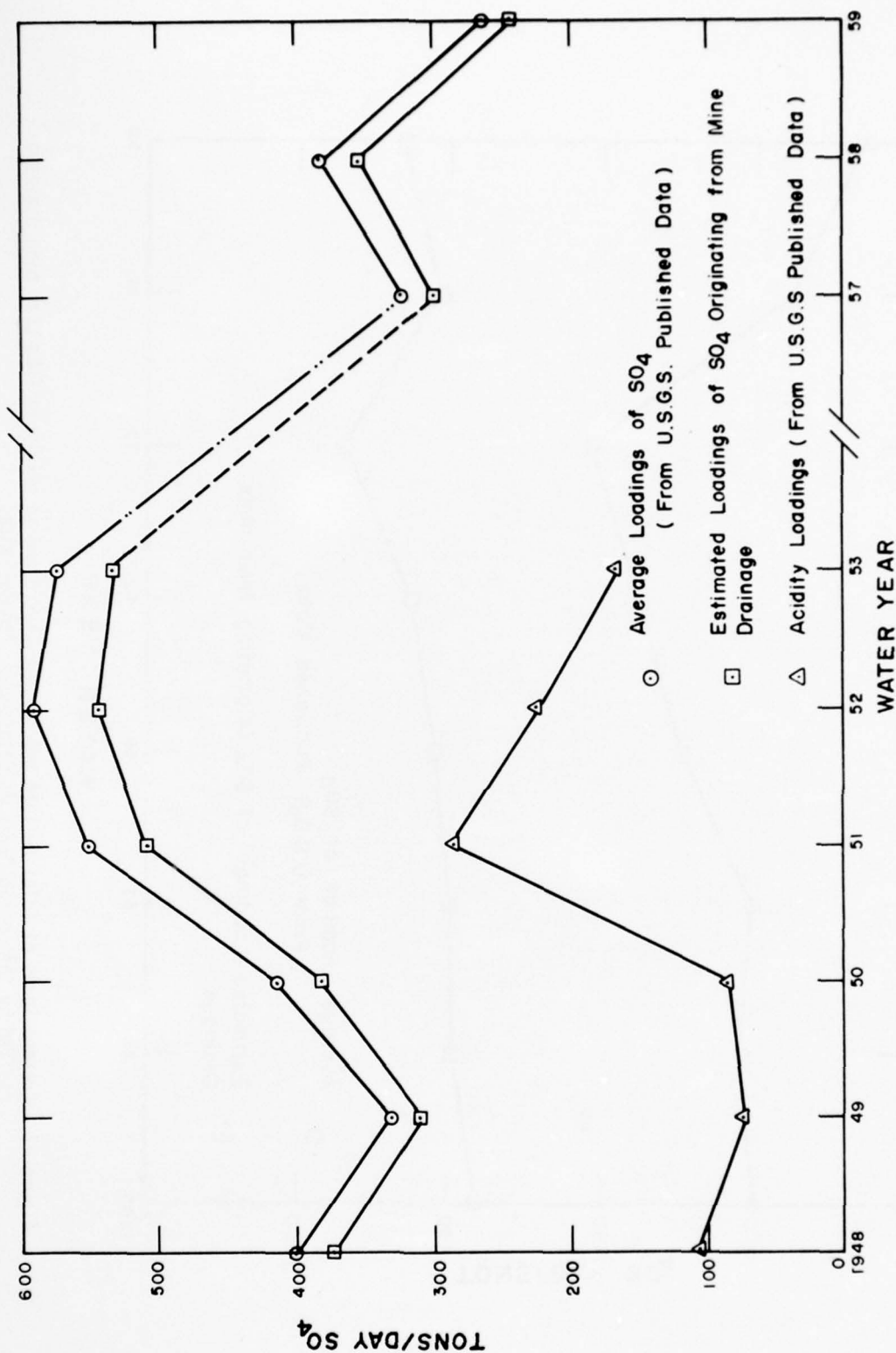


Figure 4. Average loads of acidity, total sulfate and sulfite considered to originate from coal mine drainage carried by the Schuylkill River at Berne, Pennsylvania.

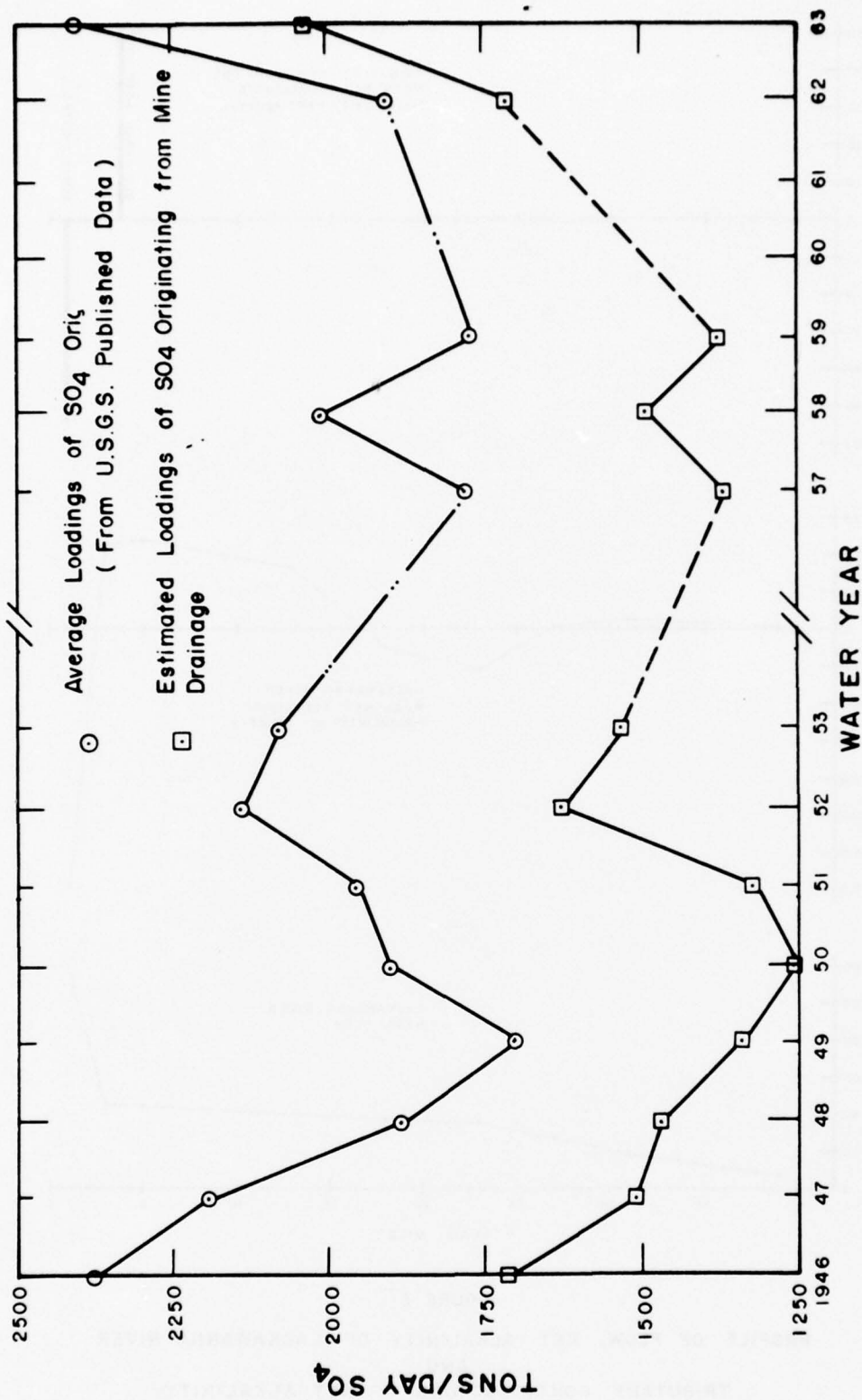


Figure 5. Average loads of total sulfate and sulfate considered to originate from coal mine drainage carried by the Susquehanna River at Danville, Pennsylvania.

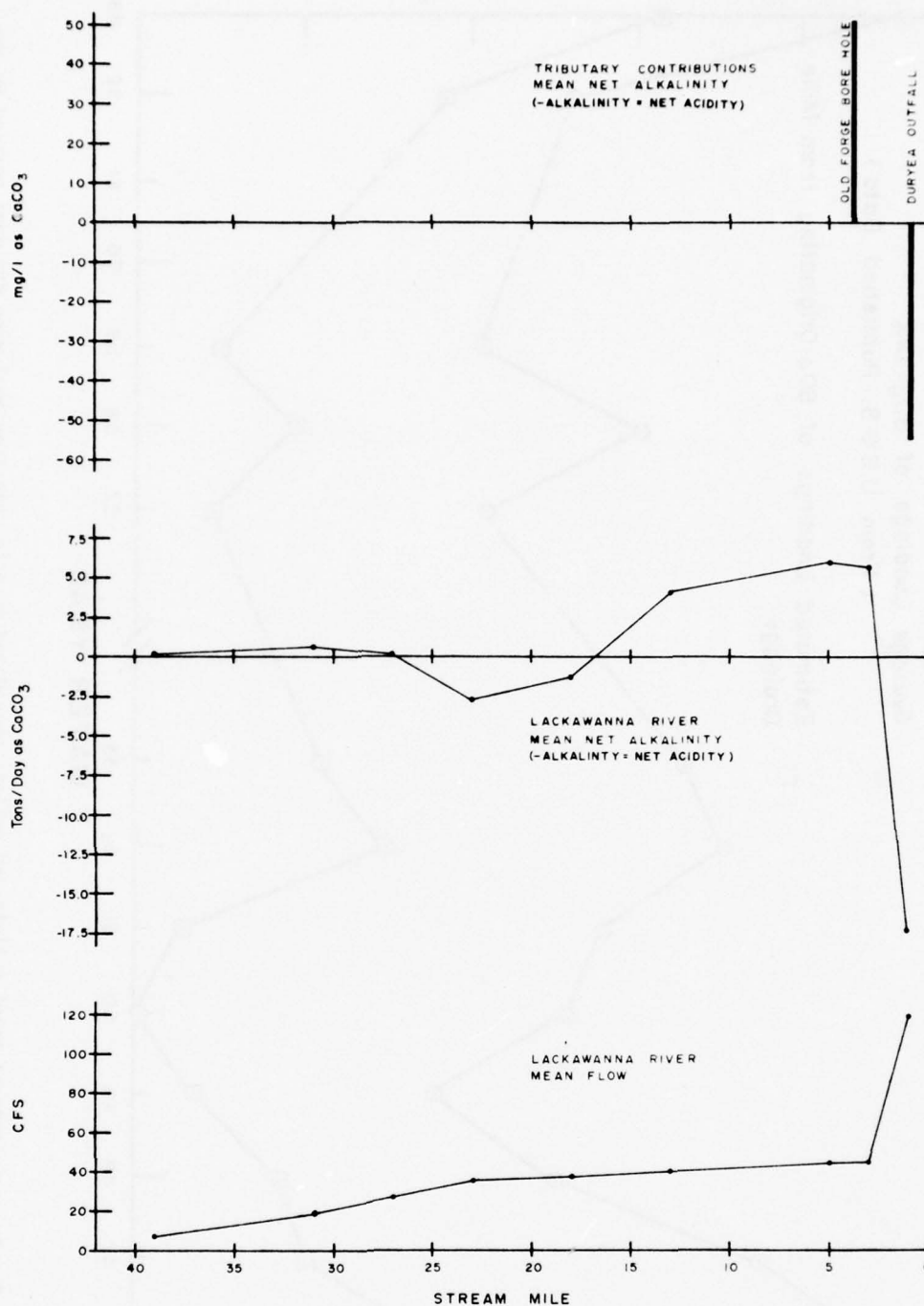


FIGURE 6
PROFILE OF FLOW, NET ALKALINITY OF LACKAWANNA RIVER
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

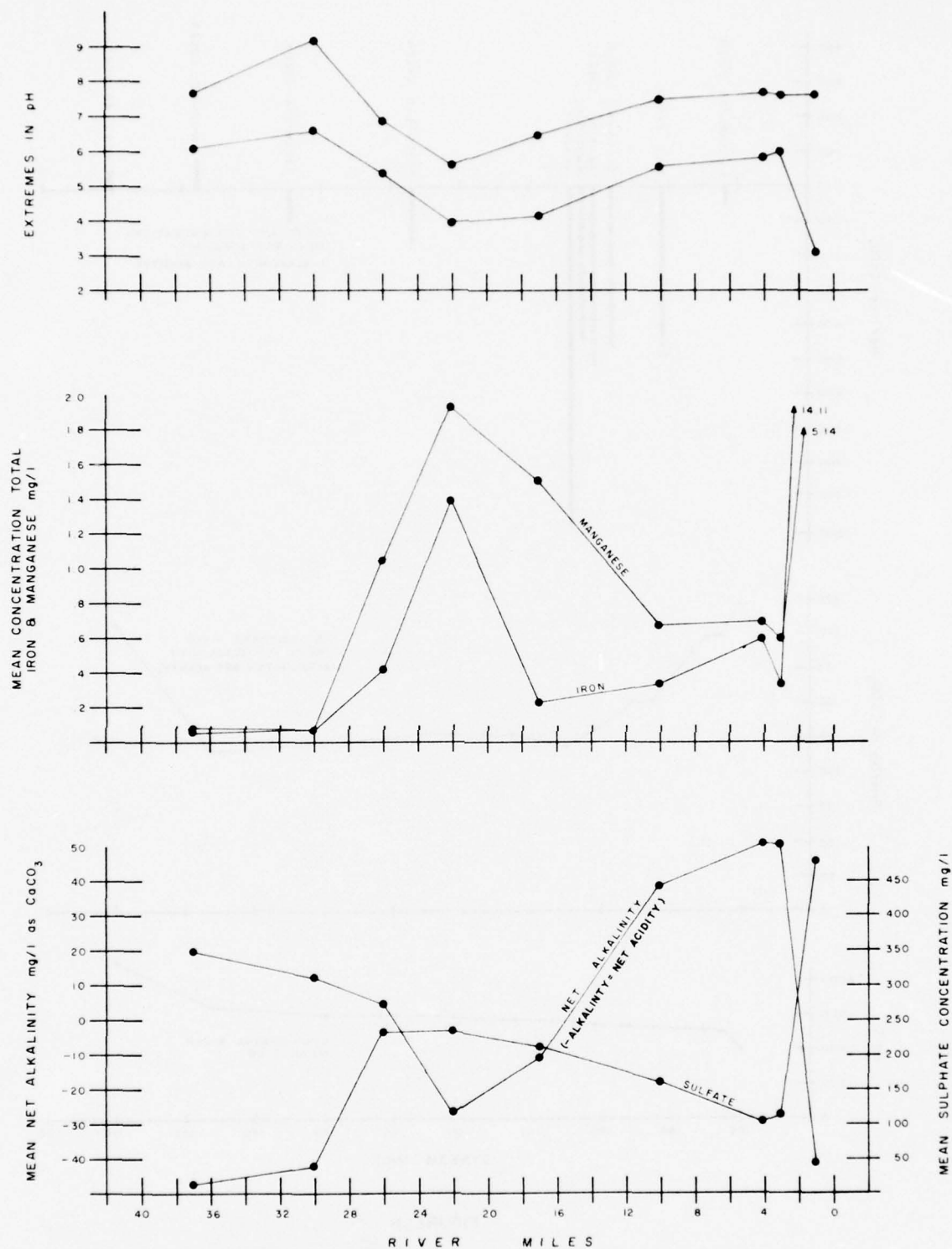


FIGURE 7 PROFILE OF pH, MANGANESE, IRON & SULFATE
CONCENTRATION AND NET ALKALINITY

LACKAWANNA RIVER

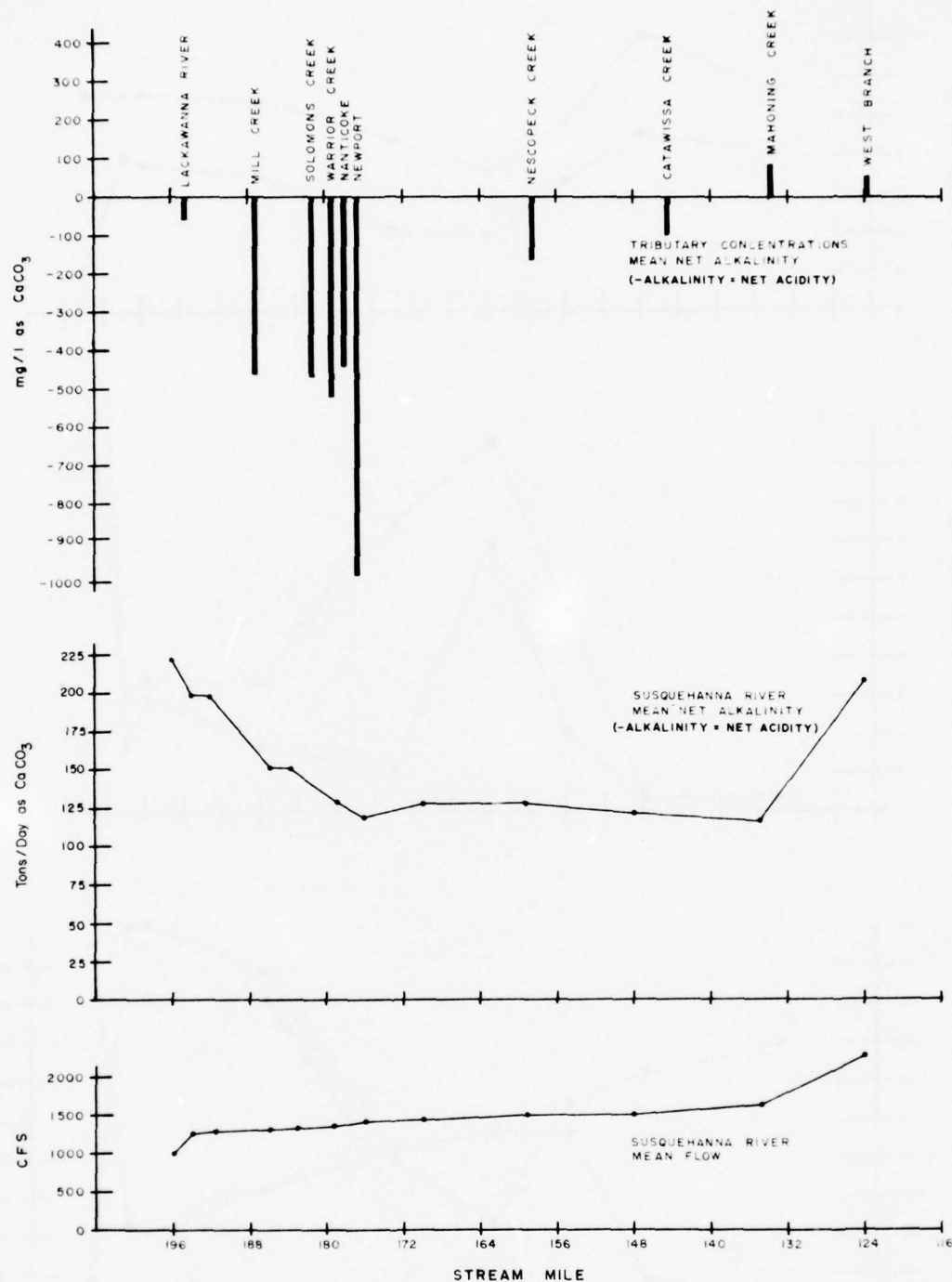


FIGURE 8
 PROFILE OF FLOW, NET ALKALINITY OF SUSQUEHANNA RIVER
 AND
 TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

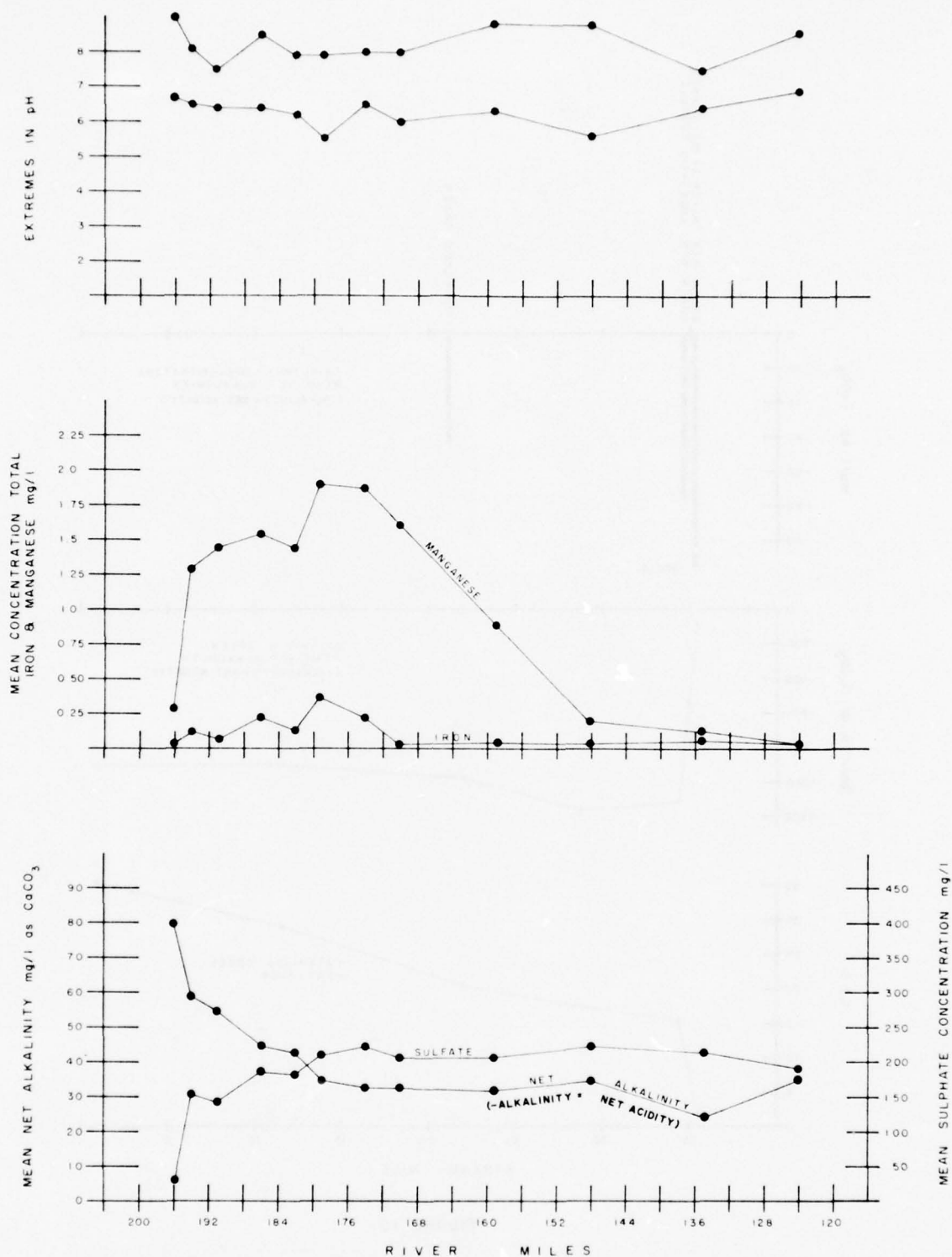


FIGURE 9 PROFILE OF pH, MANGANESE, IRON & SULFATE
 CONCENTRATION AND NET ALKALINITY
 SUSQUEHANNA RIVER

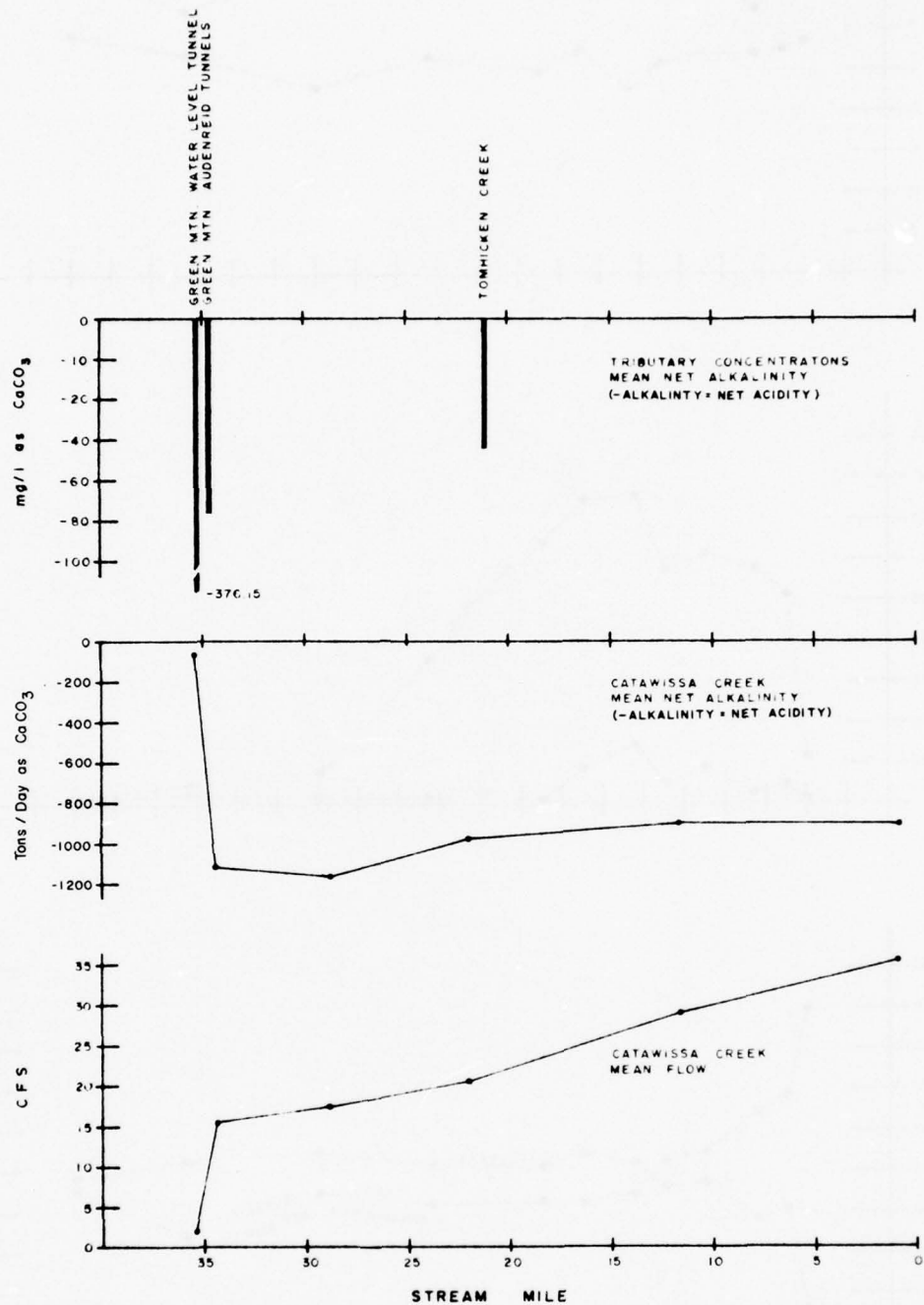


FIGURE 10
 PROFILE OF FLOW, NET ALKALINITY OF CATAWISSA CREEK
 AND
 TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

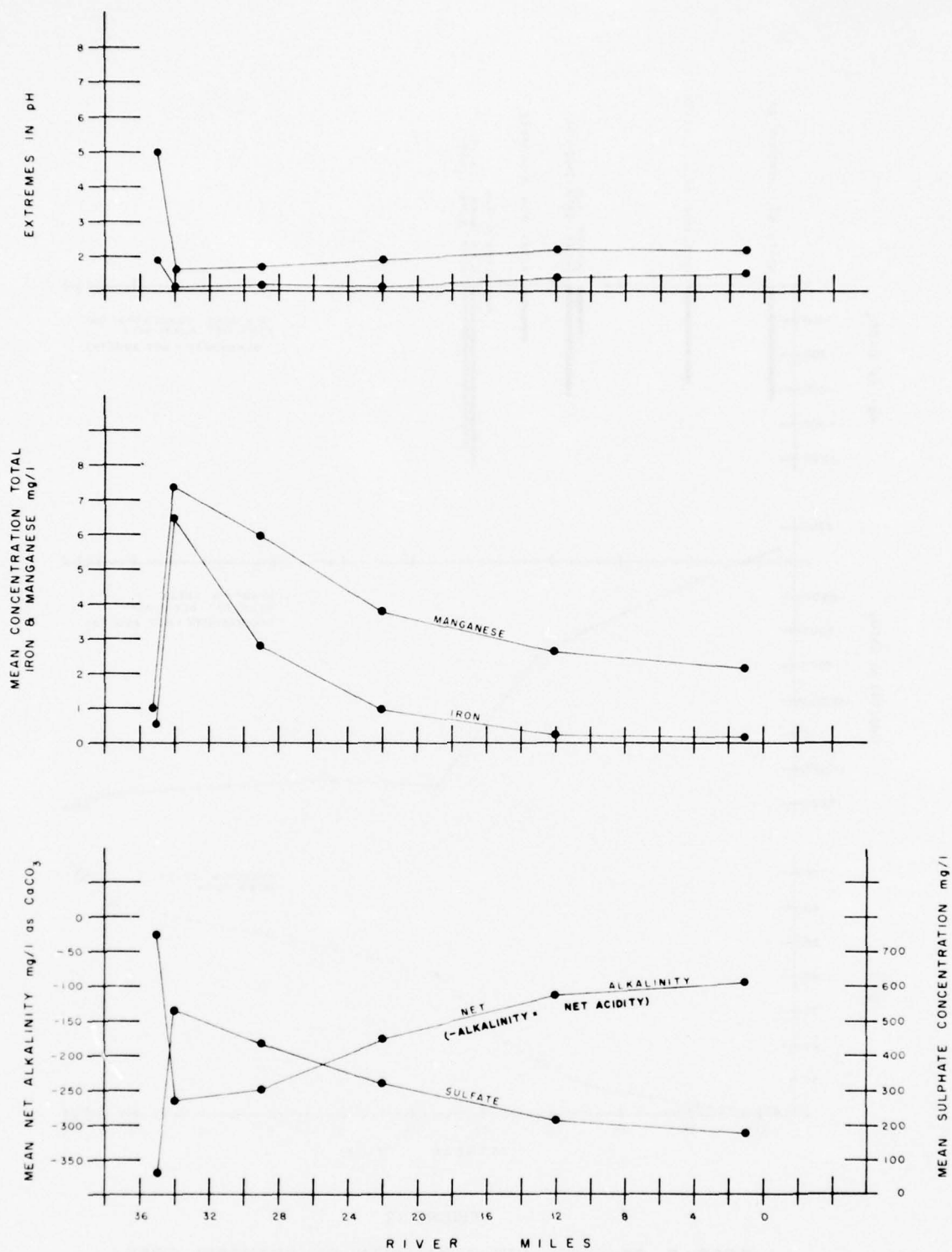


FIGURE II PROFILE OF pH, MANGANESE, IRON & SULFATE
CONCENTRATION AND NET ALKALINITY
CATAWISSA CREEK

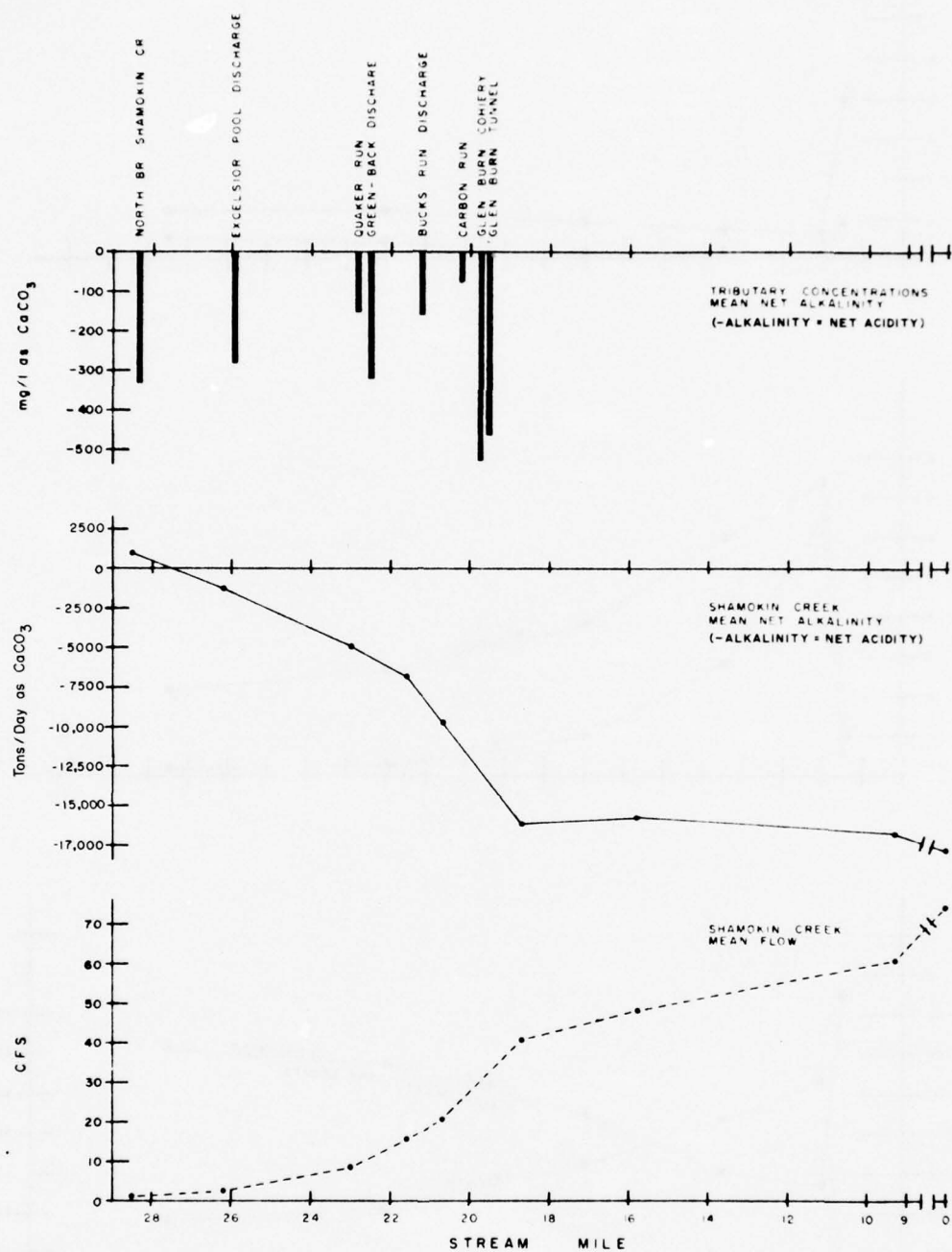


FIGURE 12
 PROFILE OF FLOW, NET ALKALINITY OF SHAMOKIN CREEK
 AND
 TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

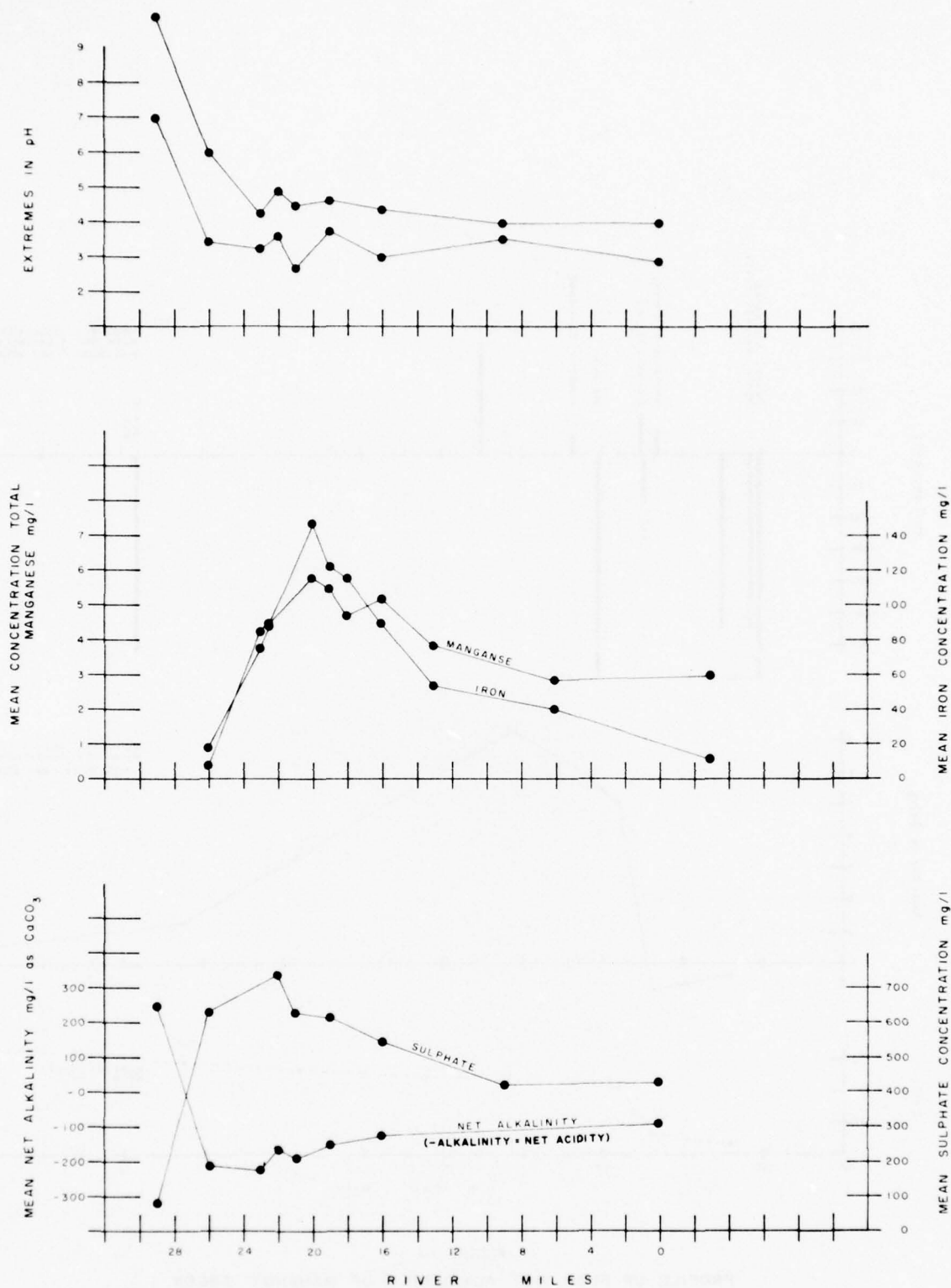


FIGURE 13 PROFILE OF pH, MANGANESE, IRON & SULFATE
CONCENTRATION AND NET ALKALINITY
SHAMOKIN CREEK

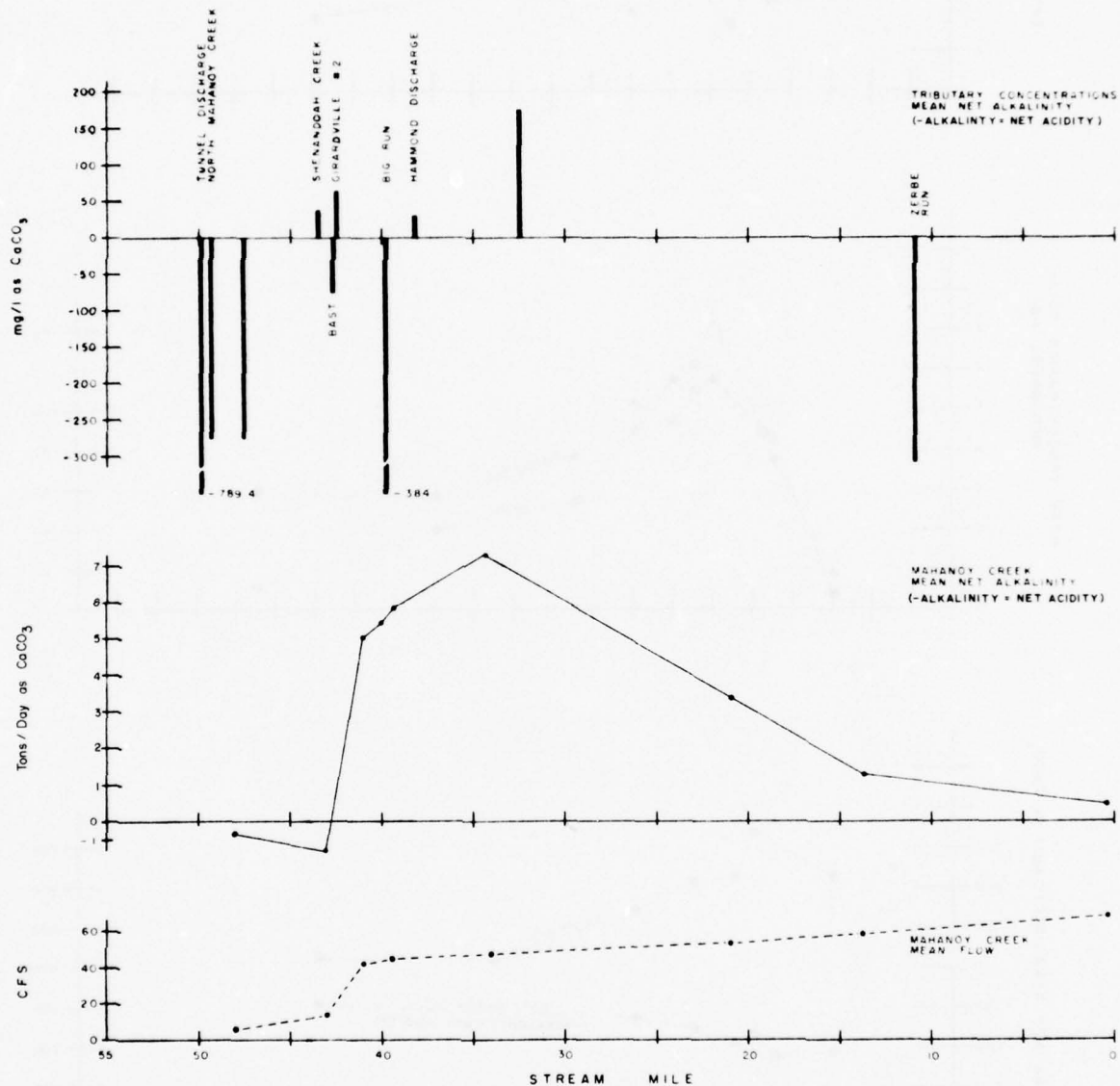


FIGURE 14
 PROFILE OF FLOW, NET ALKALINITY OF MAHANOID CREEK
 AND
 TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

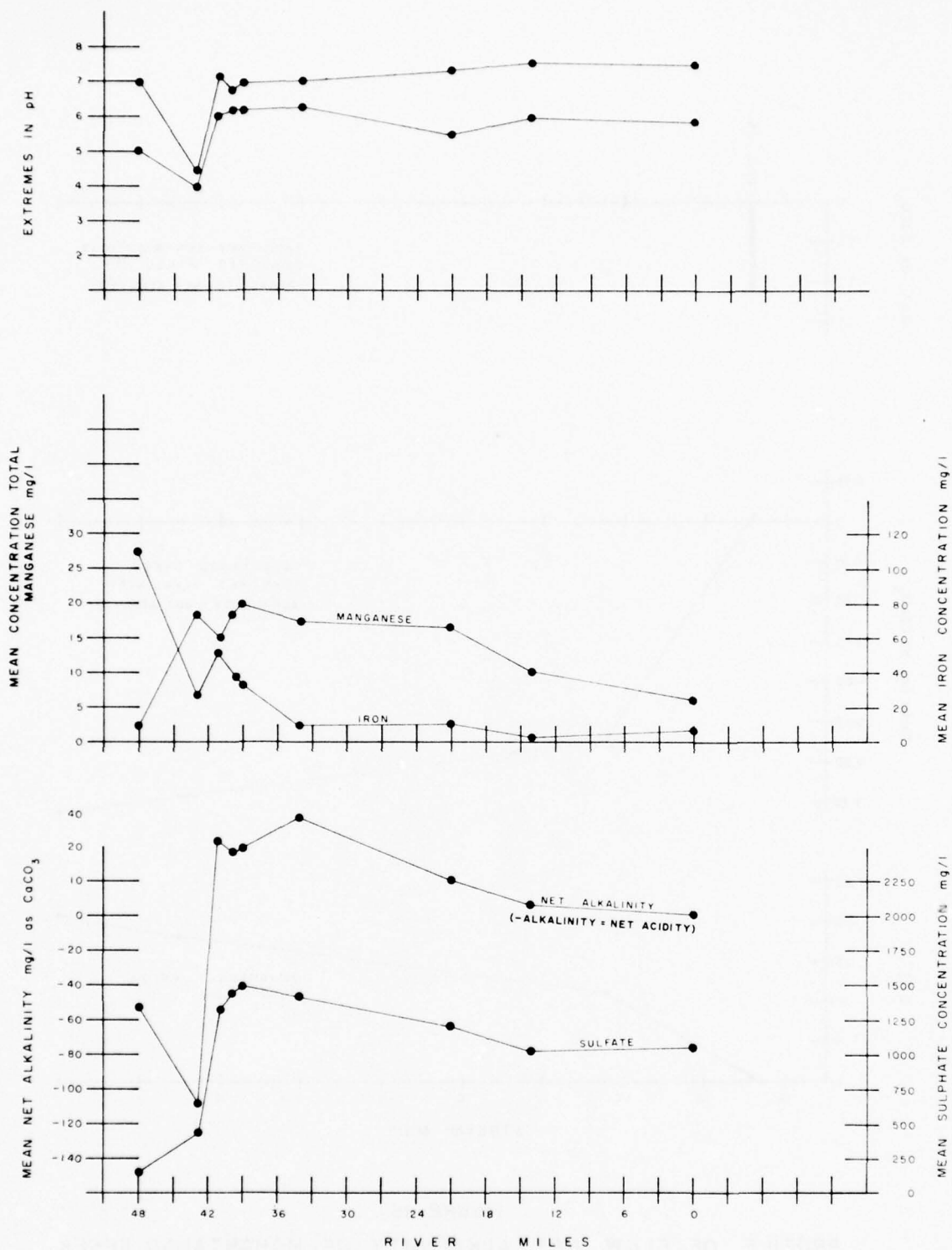


FIGURE 15 PROFILE OF pH, MANGANESE, IRON & SULFATE
CONCENTRATION AND NET ALKALINITY
MAHANAY CREEK

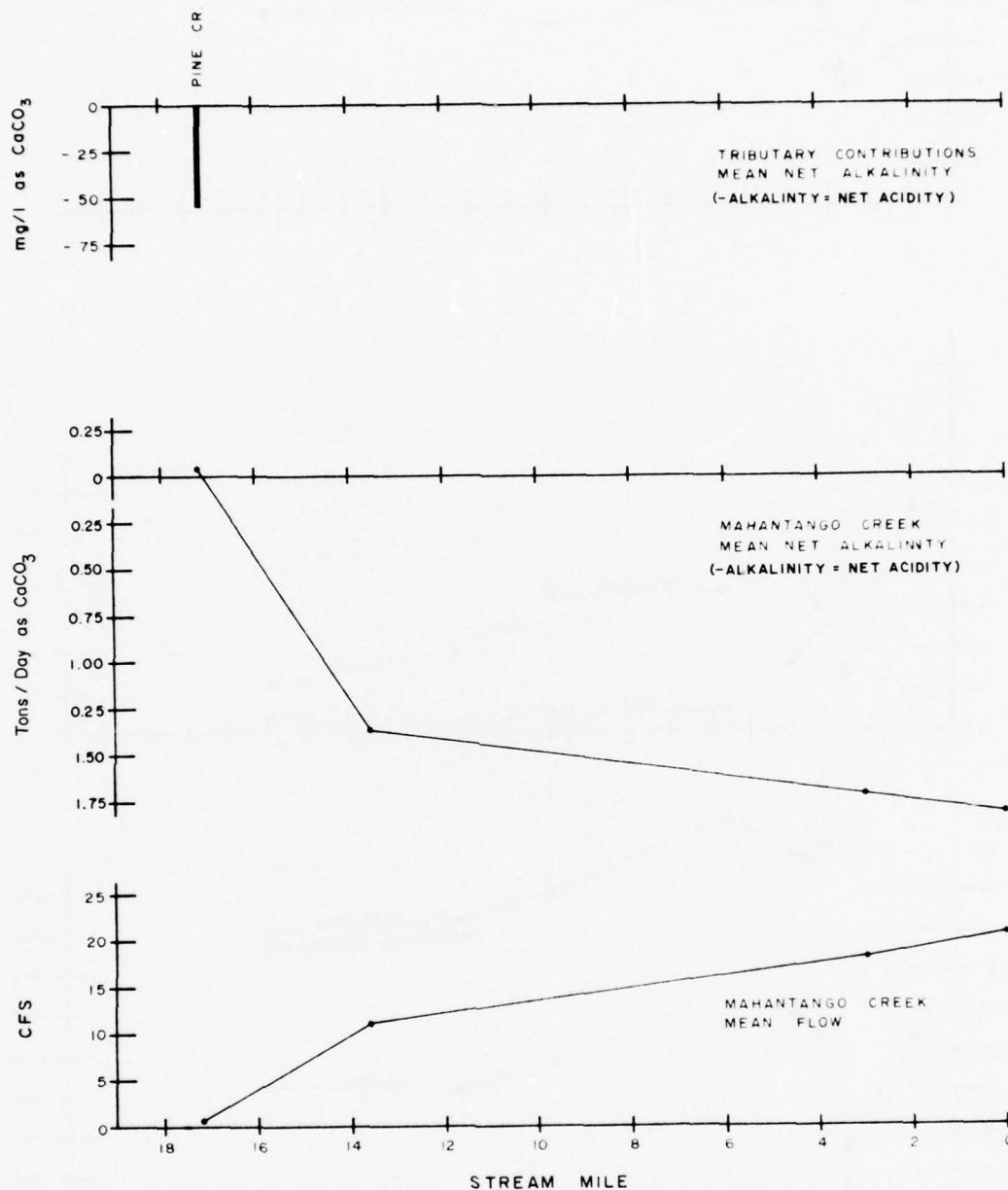


FIGURE 16
 PROFILE OF FLOW, NET ALKALINITY OF MAHANTANGO CREEK
 AND
 TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

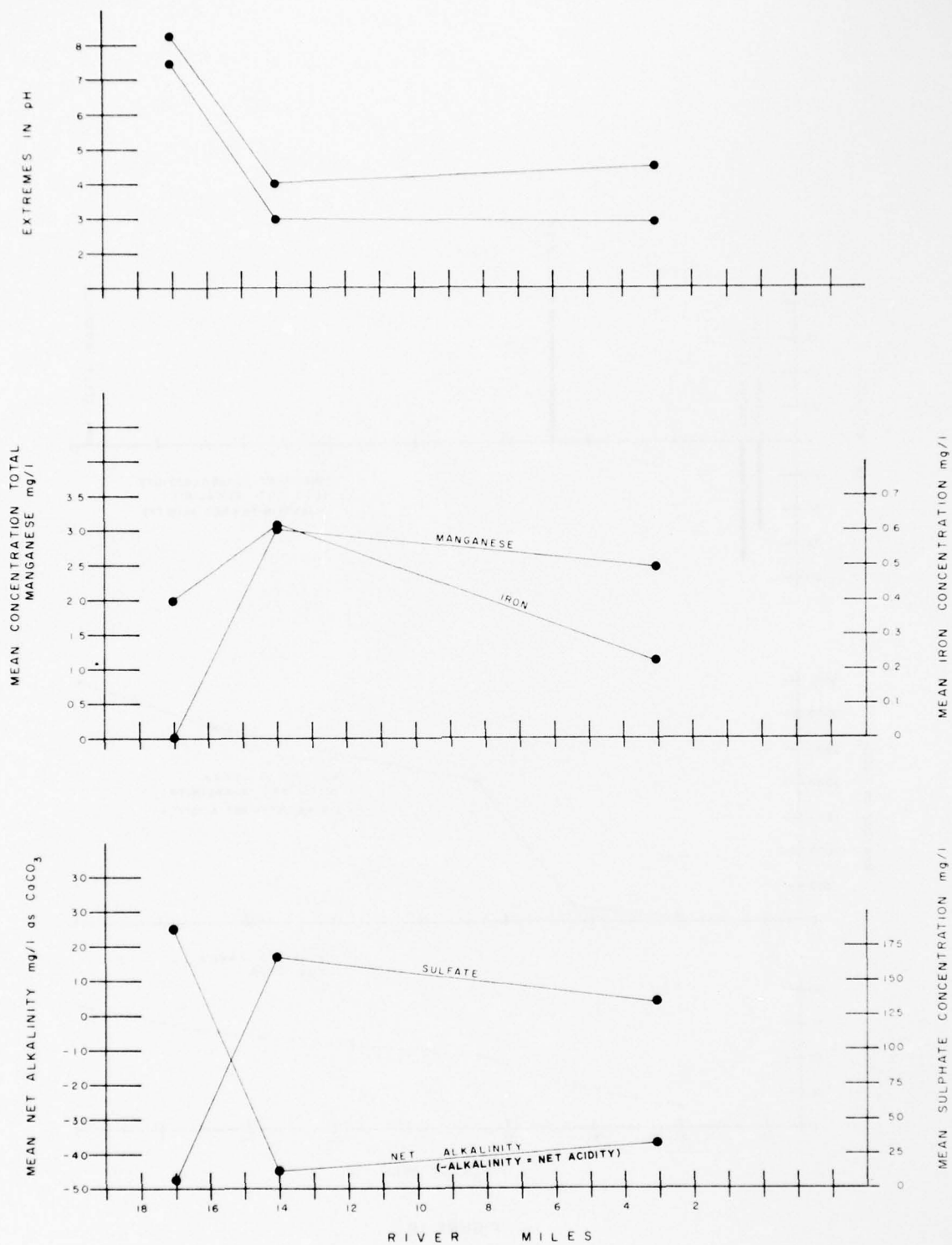


FIGURE 17 PROFILE OF pH, MANGANESE, IRON & SULFATE
CONCENTRATION AND NET ALKALINITY
MAHANTANGO CREEK

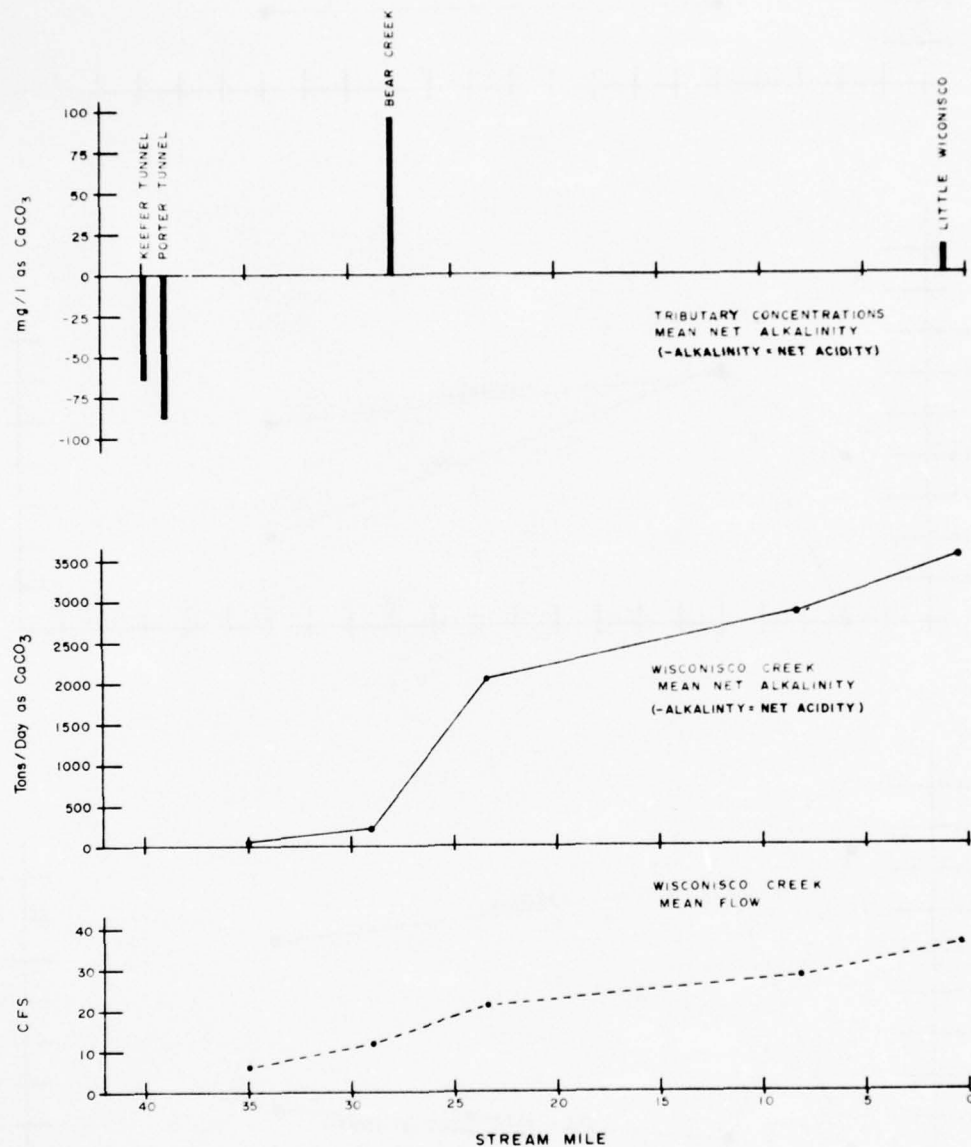


FIGURE 18

PROFILE OF FLOW, NET ALKALINITY, OF WISCONISCO CREEK
 AND TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

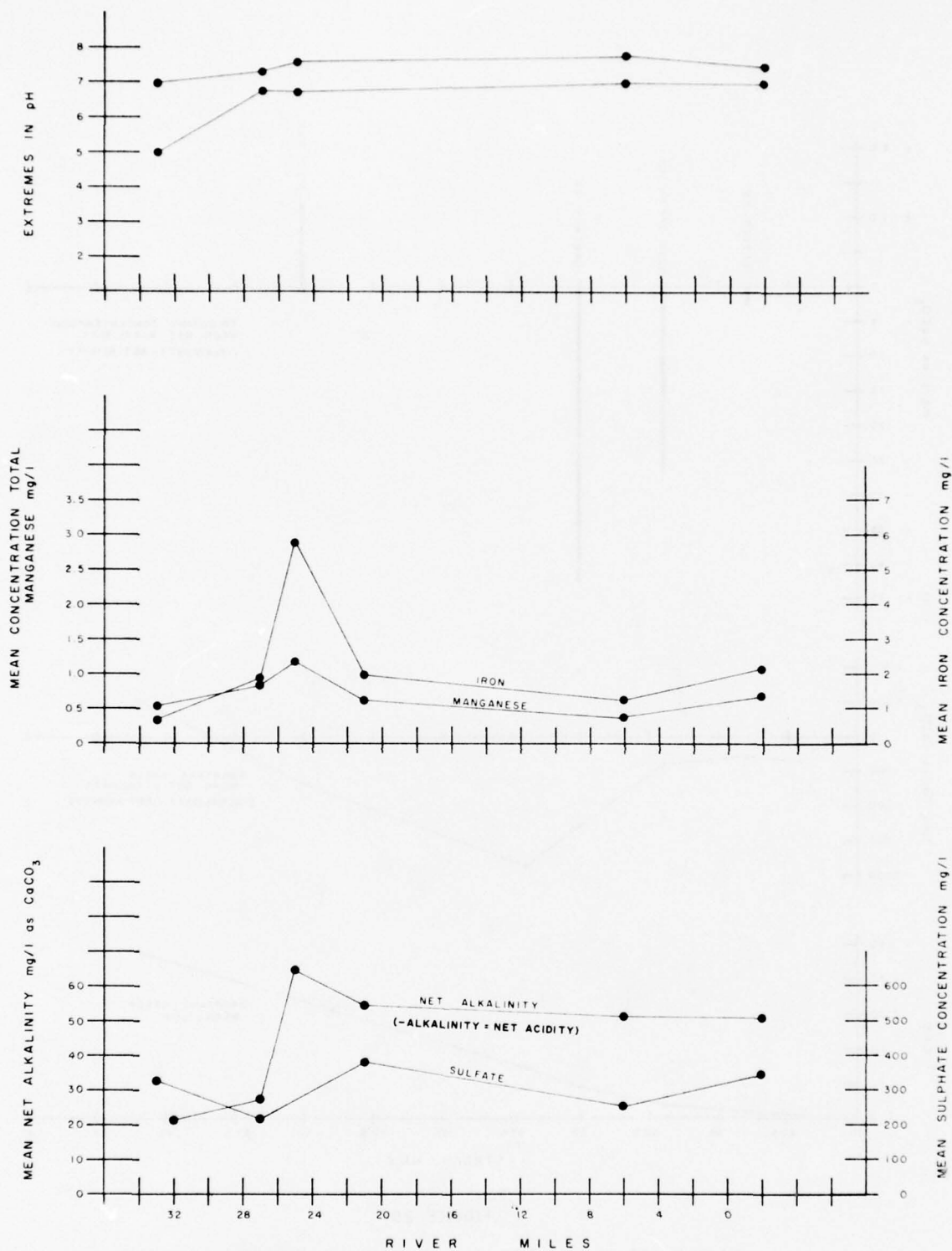


FIGURE 19 PROFILE OF pH, MANGANESE, IRON & SULFATE
CONCENTRATION AND NET ALKALINITY
WICONISCO CREEK

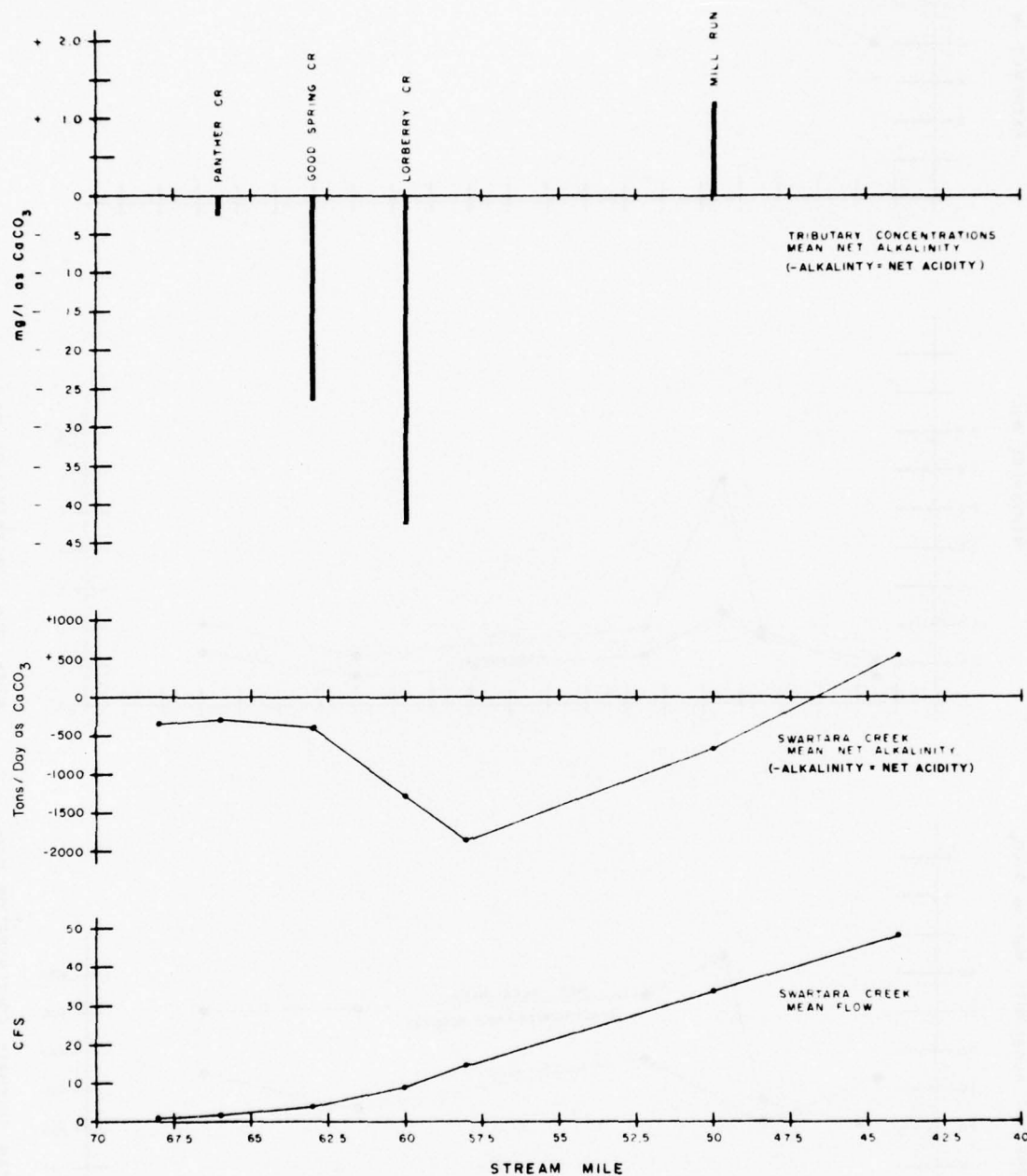


FIGURE 20
 PROFILE OF FLOW, NET ALKALINITY OF SWARTARA CREEK
 AND
 TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

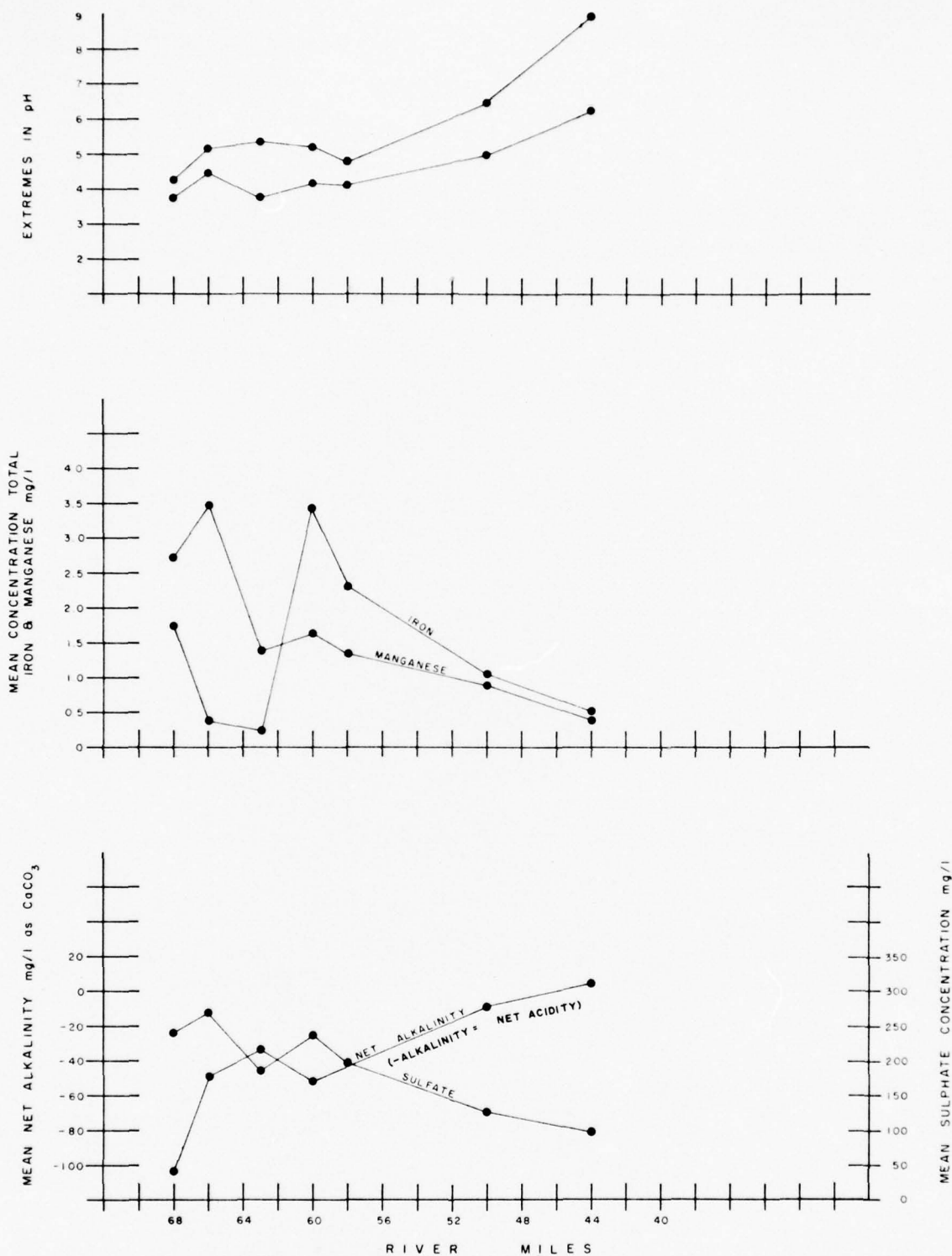


FIGURE 21 PROFILE OF pH, MANGANESE, IRON & SULFATE
 CONCENTRATION AND NET ALKALINITY
 SWATARA CREEK

Tioga River Basin

Description

The Tioga River originates in western Bradford County, Pennsylvania. The stream is 58 miles long, 45 miles of which are in Pennsylvania. It flows in a southwesterly direction into Tioga County near Blossburg, Pennsylvania, and thence in a northerly direction to join the Chemung River in New York State. Figure 22 shows the portion of the Susquehanna River basin, which includes the Tioga River basin.

Located within the Allegheny Plateau physiographic province, the Tioga basin is characterized by broad valleys and steep, rounded hills. Shale, sandstone, and coal are the dominant rock types. Most of the stream channels contain deposits of glacially derived boulders and gravel.

Coal deposits in the basin are located in the extreme headwaters and are contained in a canoe shaped synclinal basin. Of the four minable beds contained in the basin, three have been or are being mined.

Mining activity began in the Tioga basin in the 1840's reaching a maximum of approximately 1.4 million tons in 1886. Production has since declined to a level of approximately 0.4 million tons in 1964. Great emphasis is placed on surface mining. Approximately 80 percent of the coal is produced by this method. Projections of production for the Tioga River basin are shown in the following table:

Projected Bituminous Coal Production (Thousand Tons)

<u>1970</u>	<u>1985</u>	<u>2020</u>
360	460	660

Reserves of coal have been estimated at a total of 41 million short tons, with approximately 16 million short tons considered recoverable (Wessell and others, 1966).

Mine Drainage Sources and Their Effect on Stream Quality

There are only 22 major coal mine drainage sources in the Tioga River basin and 4,500 acres of unreclaimed strip-mined land. All of the drainage originates from inactive mines. Fifteen underground sources contribute 11.8 tons/day of acidity and seven surface sources contribute 1.2 tons/day of acidity.

A. Tioga River

The quality of the Tioga River above its confluence with Morris Run is not significantly affected by mine drainage. The stream is, in fact, classified as a trout stream by the Pennsylvania Fish Commission. Below this point, however, for a distance of more than 25 miles, the stream is rendered acid by mine drainage contributed by Morris Run, Coal Creek, Johnson Creek and Bear Creek (Figure 23). Downstream tributaries have weak alkalinity common to this area, but succeed in neutralizing the acid load downstream from the Cowanesque River. Biological studies indicate mine drainage inhibition of aquatic life downstream to the confluence with the Canisteo River, an additional nine miles.

The Corps of Engineers is planning a multipurpose dam and reservoir at the confluence of Crooked Creek and the Tioga River. The dam will impound both streams in separate impoundments. Mine drainage influence on the quality of the Tioga River impoundment will limit water uses. The mean net acidity at the dam site was 100 mg/l during the survey. Iron and manganese concentrations were 2.0 and 3.7 mg/l, respectively. The pH ranged from 3.7 to 4.1.

1. Johnson Creek

Although Johnson Creek contributed a weak alkaline loading to the Tioga River, it does receive mine drainage from abandoned surface and underground mines near the Village of Arnot, as shown in Figure 22, mine drainage contributed in the Arnot area overcomes the stream's alkalinity for a short distance. Mine drainage indicator concentrations are low in Johnson Creek downstream from Arnot. Two discharges with a total net acid loading of 0.2 tons/day were determined to be the major mine drainage contributors in the watershed.

2. Morris Run, Coal Creek, and Bear Creek

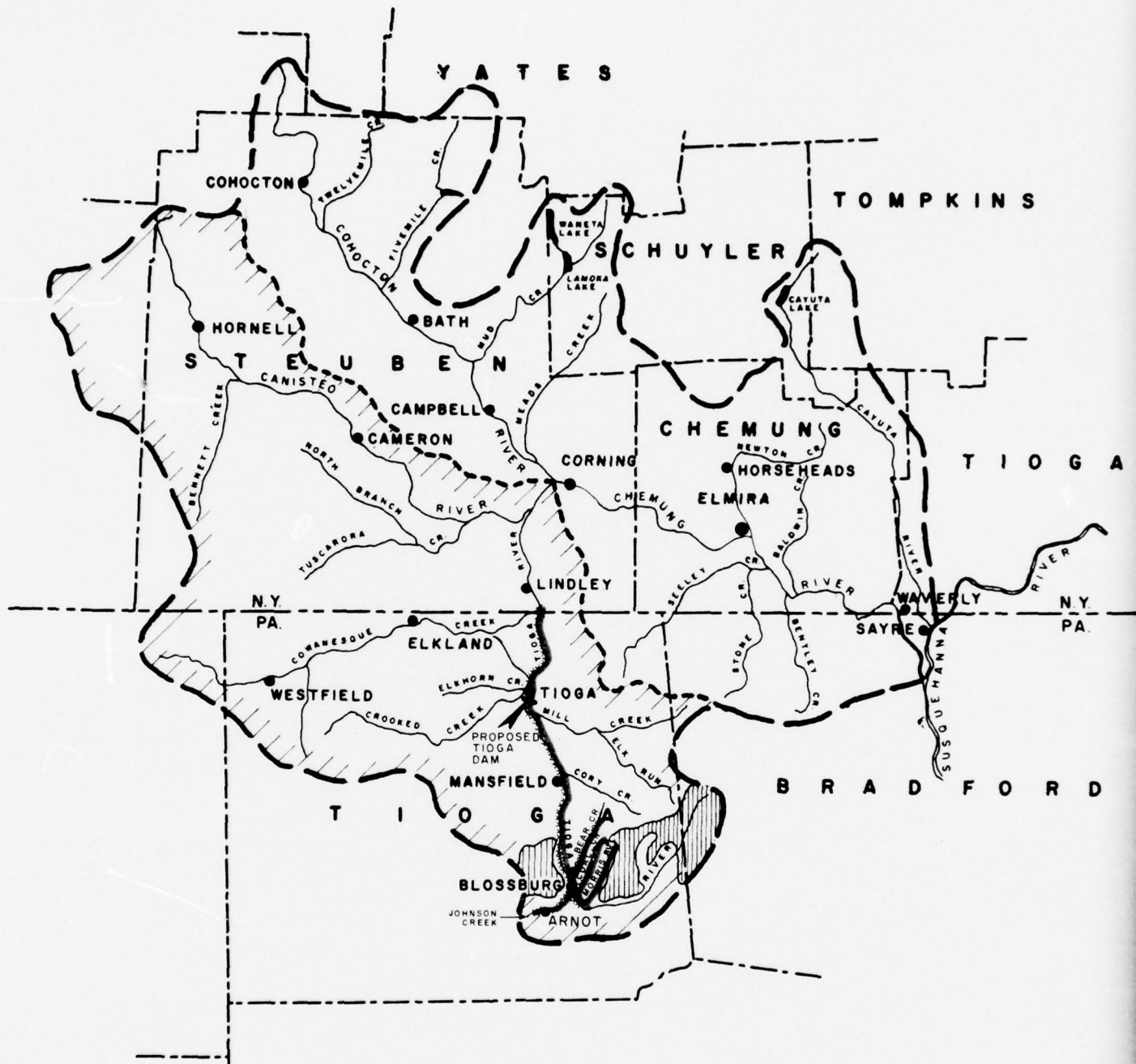
Although Morris Run, Coal Creek, and Bear Creek constitute individual sources of mine drainage to the Tioga River, they overlie a common coal deposit. Underground and surface mining has diverted surface and ground water from watershed to watershed. The three watersheds will, therefore, be discussed as a single mine drainage source to the Tioga River.

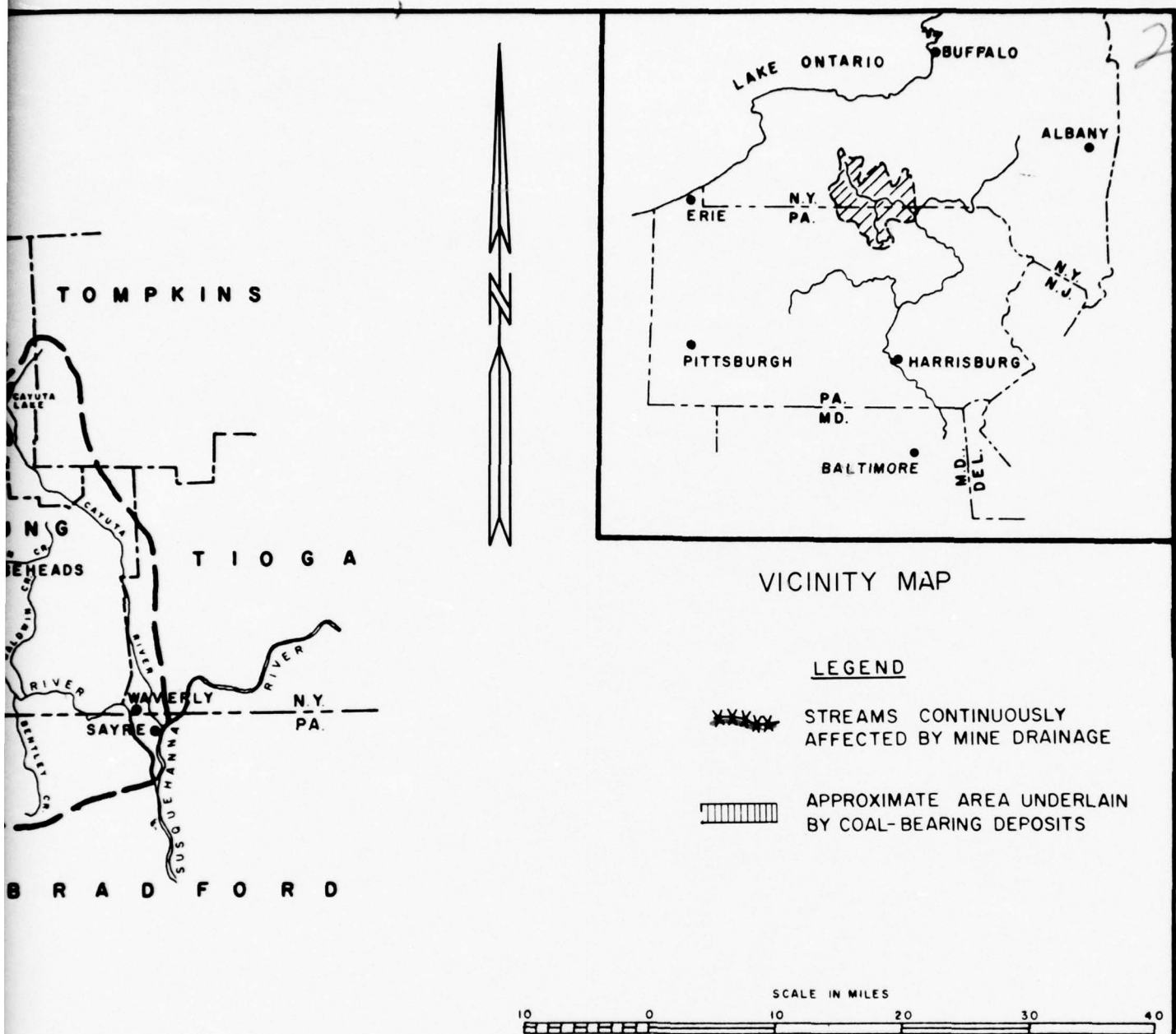
As illustrated in Figure 23, the total acidity discharged from the three streams exhausted the Tioga River's rather weak alkaline reserve and produced an acid residual of 7.75 tons/day acidity downstream from Bear Creek during the survey period. The mean acidity concentration downstream from Bear Creek was 180 mg/l. Mean iron and

manganese concentrations were 16 and 4.9 mg/l, respectively. Other mine drainage indicators were proportionately high.

Each of the three streams is acid from source to mouth, as are most of their tributaries. The quality of the three streams is essentially uniform from source to mouth. All have acidity concentrations in the 500 to 1,000 mg/l range, iron concentrations in the 20 to 100 mg/l range, and manganese concentrations in the 20 to 50 mg/l range. Morris Run receives mine drainage from two major sources and approximately 20 less significant sources. Most of the drainage originates in abandoned deep mines; however, their flow is undoubtedly influenced by contributions from strip mines, some of which lie in the Coal Creek and Bear Creek watersheds.

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APPALACHIA MINE DRAINAGE POLLUTION
REPORT

Figure 22

TIOGA RIVER BASIN

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

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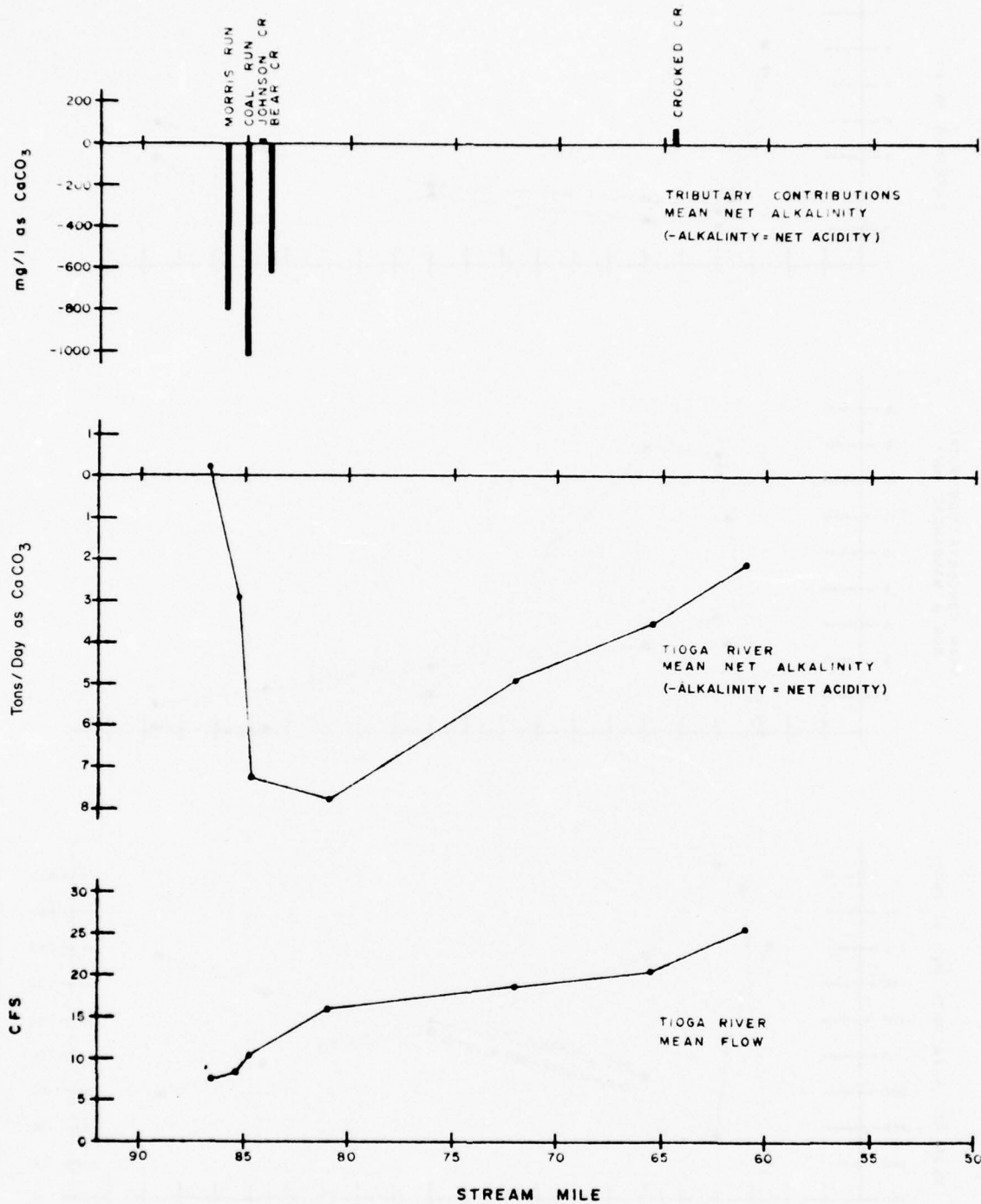


FIGURE 23
 PROFILE OF FLOW, NET ALKALINITY OF TIOGA RIVER
 AND
 TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

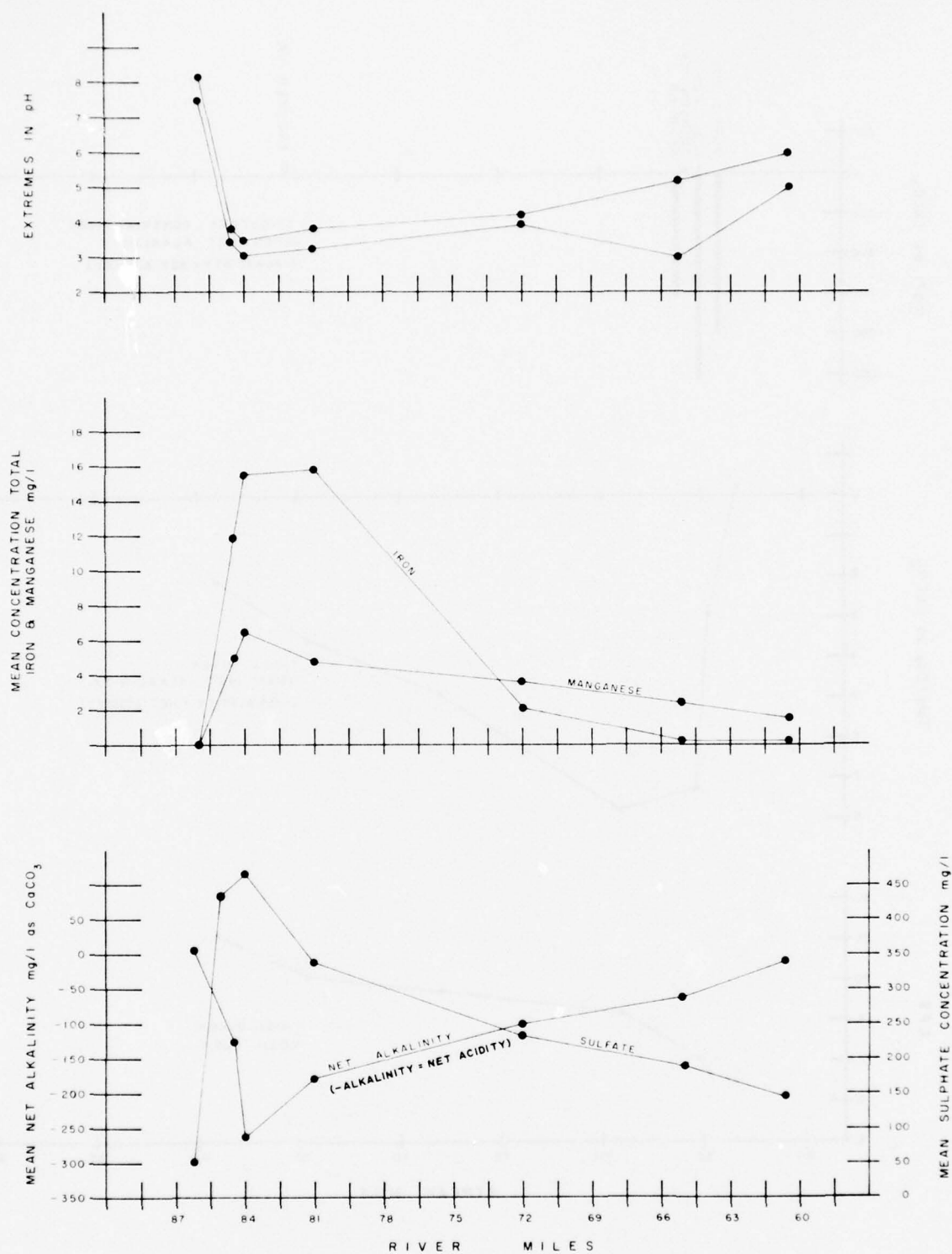


FIGURE 24 PROFILE OF pH, MANGANESE, IRON & SULFATE CONCENTRATION AND NET ALKALINITY

TIOGA RIVER

West Branch Susquehanna River Basin

Description

The West Branch Susquehanna River drains an area of 6,913 square miles in the west central portion of the Susquehanna River basin (Figure 25). The basin lies entirely within Pennsylvania and includes all or portions of 19 counties. The basin is bounded on the north by the Genesee and Chemung River basins, on the south by the Juniata River basin, on the east by the Susquehanna River basin and on the west by the Allegheny River basin. The West Branch Susquehanna River has its source in northwestern Cambria County and flows a distance of 240 miles to its confluence with the Susquehanna River at Northumberland.

The upper portion of the basin lies within the high tablelands of the Appalachian Plateau Province. At Lock Haven, the river breaks through the Allegheny Front, the escarpment which divides the Appalachian Plateau and Valley and Ridge Provinces, then flows approximately 70 miles through the Valley and Ridge Province to its confluence with the Susquehanna River. In the Appalachian Plateau Province, stream valleys are narrow and are flanked by high, steep hills. In the Valley and Ridge Province, valleys are generally broad and fertile and are bounded by rugged forested mountains. Moderate to steep gradients of streams in the Appalachian Plateau Province provide considerable turbulence and excellent mixing characteristics. The combination of low gradient and a wide, shallow channel configuration combine to produce poor mixing characteristics in the Valley and Ridge Province.

Major tributaries of the West Branch, their drainage areas and the mile point of their confluence with the main stream are tabulated below.

Name	Drainage Area (square miles)	Mile Point of Confluence
Loyalsock Creek	493	35
Lycoming Creek	276	41
Pine Creek	973	67
North Bald Eagle Creek	782	78
Kettle Creek	239	104
Sinnemahoning Creek	1,033	110
Moshannon Creek	288	136
Clearfield Creek	396	172
Chest Creek	132	205

Consolidated rocks that outcrop in the area are all of Paleozoic age and belong primarily to the Pennsylvanian and Mississippian Systems.

The Pennsylvanian age Conemaugh and Allegheny Formations contain the coal beds of economic significance.

It is estimated that approximately 4,400 mines have been opened in the basin (Lorenz, 1966) most of which have long been abandoned. Estimates by watershed as of 1962 indicate the opening of about 830 mines in the Moshannon Creek watershed, 1,150 in the Clearfield Creek watershed, 330 in the Bennett Branch Sinnemahoning Creek watershed and 180 in the Beech Creek watershed. The remaining mines were opened in the watersheds of minor tributaries to the West Branch upstream from the mouth of Loyalsock Creek.

Of the original bituminous coal reserves in the subbasin estimated to be 4,140 million tons in 1928 (Reese and Sisler, 1928) about 2,535 million tons still remained as recoverable reserves in 1963 (Central Pennsylvania Coal Producers Association). An estimated 1,334 million tons, more than half of the recoverable reserves, underlie Clearfield County. Coal production in the basin has been relatively stable, averaging about 9 million tons per year since 1945. Recently, Clearfield and Centre Counties have accounted for about 80 percent of the production in the basin (Wessel and others, 1964). Prior to 1945, deep mines accounted for most of the coal production in the basin; however, development of large earth-moving equipment during World War II greatly stimulated surface mining activity. Strip mining accounted for 45 percent of the Susquehanna River basin's production in 1945, 77 percent in 1955, and 84 percent in 1962. A gradual increase in production to 13.4 million tons in 2020 is projected (Wessel and others, 1964).

Mine Drainage Sources and Their Effect on Stream Quality

As shown in the table on the following page, there are presently about 967 major mine drainage sources in the West Branch basin. The drainage from these sources is causing continuous significant degradation of 540 miles of streams and intermittent significant pollution of 600 miles of streams.

For the years 1945-1953 and 1957-1958 the average sulfate loading was about 1,100 tons/day in the West Branch at Lewisburg. About 695 tons/day of this sulfate originated as mine drainage acidity. This estimate of the amount of acidity formed in the West Branch basin is substantiated by water quality data from Lock Haven (Figure 26) where sulfate loadings for the years 1946-1951, 1959, and 1962-1963 averaged 870 tons/day, with about 685 tons/day originating as mine drainage acidity. It is estimated that 250 tons/day of unneutralized acidity enters streams in the basin.

Mine Drainage Sources and Net
Acidity Contributions
West Branch Susquehanna River Basin

Area	Sub-Area	Active Operations			Inactive Operations						Total Sources		
		Underground Mines		Surface Mines	Underground Mines		Surface Mines	Other Sources ^{1/}			No. of Sources		Net Acidity
		No. of Sources	Net Acidity ^{2/}	No. of Sources	No. of Sources	Net Acidity	No. of Sources	Net Acidity	No. of Sources	Net Acidity	No. of Sources	Net Acidity	
West Branch Susquehanna River Headwaters Tributaries (Above Chest Creek)		5	5,000	2	100	22,500	97	1,900	7	24,000	142	53,500	
	Chest Creek	4	100	5	500	7,100	48	1,100	4	100	84	8,900	
Anderson Creek				3	500	2,700	13	4,200			30	7,400	
	Clearfield Creek	1	100			19,200	50	15,000	22	2,400	95	36,900	
Moshannon Creek				2	200	80,600	89	50,600	20	4,800	158	136,000	
	Sinnemahoning Creek	3	3,600			27,100	82	2,200	3	100	100	33,000	
Beech Creek		1		5	1,200	8,000	35	12,000	21	800	113	22,000	
	Pine Creek					11,500	22	3,100			26	14,600	
Minor Tributaries (Below Chest Creek)		5	4,000			37,900	124	14,500	27	80,300	219	186,700	
	(Sub-Total)	19	12,800	17	2,500	266,600	560	104,600	104	112,500	967	499,000	

^{1/} Other inactive sources are abandoned refuse piles and seepages that can not be identified with specific sources.

^{2/} Net acidity in pounds per day.

A detailed discussion of the mine drainage sources in the West Branch Susquehanna River basin, and their effect on stream quality follows:

A. Headwaters to Chest Creek

A total of 142 major mine discharges have been located in this drainage area contributing approximately 27 tons/day net acidity. Most of the acid drainage in this reach originates in abandoned underground mines within the drainage of the upper nine miles of the West Branch. Numerous drainage sources exist in the remainder of the reach above Chest Creek, but they are alkaline.

The first major addition of mine drainage in this reach is the pumped discharge from an active deep mine. The discharge contributed a loading of 2 tons/day net acidity. This contribution was primarily responsible for the mean acidity concentration of 450 mg/l and an associated loading of 2.4 tons/day net acidity recorded on the West Branch about two miles downstream at mile 236 (see Figures 27 and 28).

Major mine drainage contributors within the next seven miles include three spoil piles and four abandoned deep mines. Their total contribution was 15 tons/day net acidity. The three spoil piles were responsible for about 30 percent of this total.

Between mile 229 and 220 the acidity concentration declined to 50 mg/l. The reduction is probably the result of the neutralizing action of naturally alkaline tributaries to the reach. Several of these tributaries have alkalinities in excess of 150 mg/l. From mile 220 to its confluence with Chest Creek, the West Branch does not exhibit a significant change in alkalinity, although a slight increase in other mine drainage indicators is evident.

In general, concentrations of mine drainage indicators declined throughout the length of the reach from the headwaters to Chest Creek. Mean iron and manganese concentrations, which were 120 and 3.6 mg/l, respectively, at the head of the reach, declined to 1.1 and 2.5 mg/l, respectively. Sulfates declined from 1,300 mg/l to 550 mg/l (see Figure 28).

1. Chest Creek

Chest Creek, during the survey period, contributed about 1 ton/day net alkalinity to the West Branch. Preliminary reconnaissance data indicate that, although Chest Creek was alkaline at its

mouth during the survey period, a 3-mile reach is degraded by mine drainage that originates in the watershed of Brubaker Run (Figure 25). Mining activity has been very heavy in the Brubaker Run watershed. Sources of mine drainage include both underground and strip mines and refuse piles. Acid loads on the order of 2.0 tons/day from Brubaker Run degrade the quality of Chest Creek from its confluence with Brubaker Run to Westover. At Westover, a large alkaline discharge from a tannery neutralizes the acidity but significant levels of other mine drainage indicators remain.

A total of 84 drainage sources were located in the Chest Creek watershed contributing a total of 4.2 tons/day of acidity. Forty-two of these are in Brubaker Run, five of which discharge about 70 percent of the acidity that originates in the Chest Creek watershed. Inactive underground mines are the primary drainage source, but inactive surface mines are also significant contributors.

B. West Branch Susquehanna River-Chest Creek to Clearfield Creek

The West Branch Susquehanna River, from Chest Creek to Anderson Creek, varies between weakly acid and weakly alkaline, depending upon hydrologic conditions. The minor tributaries to this reach, although in general slightly influenced by mine drainage, contribute alkalinity. Acid contributions by Anderson Creek, Montgomery Creek, and Wolf Creek, totaling about 1.5 tons/day, were outweighed by alkaline contributions within the reach from Anderson Creek to Clearfield Creek.

The pH within the reach between Chest Creek and Clearfield Creek ranged from 3.1 to 7.6, the mean total iron concentration declined from 1.1 mg/l to 0.25 mg/l, and manganese and sulfate concentrations declined from 2.5 mg/l and 553 mg/l, respectively, to 0.05 mg/l and 270 mg/l, respectively. Fish and other aquatic life have been observed in this reach, although population is probably somewhat depressed by residual amounts of mine drainage.

1. Anderson Creek

Anderson Creek contributed an average of nearly 1 ton/day net acidity to the West Branch during the survey period. Most mining activity has been confined to the lower reaches of the watershed, and stream quality has not been seriously impaired by mine drainage upstream from the confluence with Little Anderson Creek (see Figure 25). Downstream from Little Anderson Creek, the stream is rendered acid by mine drainage from Little Anderson Creek. Minor tributaries downstream from Little Anderson Creek add to the acid loading of Anderson Creek. Mean total iron, manganese, and sulfate concentrations measured at the mouth were 3.9 mg/l, 3.4 mg/l, and 160 mg/l, respectively.

Most of the mine drainage in the watershed originates in abandoned mines. Although 30 discharges were observed, about 70 percent of the acid load measured originates in six discharges.

2. Clearfield Creek

Clearfield Creek is rendered acid by mine drainage from its source to its mouth. During an eight-week survey period in 1966, the stream contributed an average of 29 tons/day acidity to the West Branch. At the mouth, a mean net acidity concentration of 115 mg/l was measured. Total iron concentrations were relatively low (1.4 mg/l); however, other mine drainage indicators were present in high concentrations.

Although mining activity has been very extensive throughout most of the watershed, about 45 percent of the acid load in Clearfield Creek originates in 10 tributaries that have a combined drainage area of 95 square miles, or about 25 percent of the area of the Clearfield Creek watershed. The streams responsible for much of the acid load in Clearfield Creek are listed in Table 3 and their locations are indicated in Figure 29.

Table 3 - Principal Tributaries Contributing Mine Drainage to Clearfield Creek

Stream	Stream Mile (on Clearfield Creek)	Drainage Area (sq. mile)	Net Acid Loading (tons/day)
Roaring Run	1.3	12.2	1.0
Long Run	4.2	4.0	1.0
Potts Run	18.2	15.4	1.5
Upper Morgan Run	19.6	12.2	1.5
Lost Run	22.1	2.5	2.0
Japling Run	24.9	3.2	2.5
Muddy Run	25.5	30.6	13.5
Powell Run	45.7	11.2	1.3
Bluebaker Run	49.7	2.5	0.8
Trap Run	61.6	1.5	1.8

Ninety-five major mine drainage discharges were located in the Clearfield Creek basin. Field analysis of the discharges indicated that 16 of these major discharges, with a combined flow of 11 cfs, contributed about 15 tons acidity per day, or about 60 percent of the acid load at the mouth.

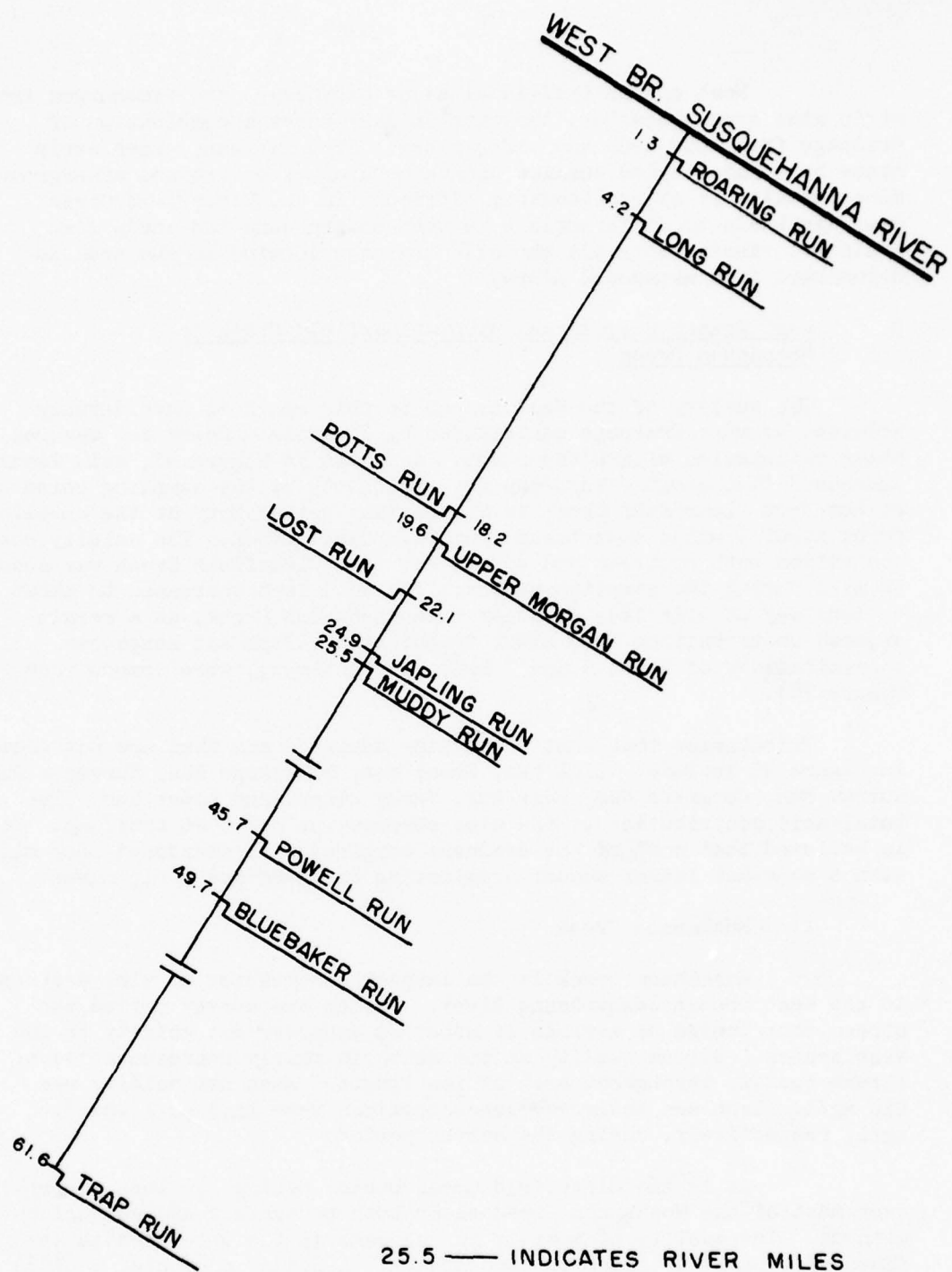


Figure 29. Schematic diagram of streams affected by coal mine drainage pollution in the Clearfield Creek Watershed.

Most of the individual major discharges are discharges from strip mine areas; however, they are in many cases a combination of drainage from both deep and strip mines. Since in many cases strip mines have intercepted shallow underground mines or crossed underground mine portals, it is particularly difficult in the Clearfield Creek drainage basin to differentiate between underground and strip mine drainage. Essentially all the acid drainage located in the area is discharged from abandoned mines.

● C. West Branch Susquehanna River-Clearfield Creek to Moshannon Creek

The quality of the West Branch in this reach is considerably affected by mine drainage contributed by Clearfield Creek and several minor tributaries within the reach. As shown in Figure 27, acid loadings increased from about 2 tons/day net alkalinity at the sampling point upstream from Clearfield Creek to 26 tons/day net acidity at the sampling point about 9 miles downstream from Clearfield Creek. The acidity concentration both upstream and downstream from Clearfield Creek was about 50 mg/l during the sampling period. The acid load increased to about 54 tons/day at mile 144, upstream from Moshannon Creek, as a result of acid contributions from minor tributaries. Iron and manganese concentrations of about 6 and 7 mg/l, respectively, were common (see Figure 28).

Tributaries that contribute mine drainage and that are not shown in Figure 25 include: Lick Run, Trout Run, Millstone Run, Surveyor Run, Murray Run, Congress Run, Deer Run, Sandy Creek, and Alder Run. The total acid contribution by the nine streams was about 20 tons/day. It is believed that most of the drainage originates in abandoned deep mines, with a somewhat lesser amount originating in abandoned strip mines.

1. Moshannon Creek

Moshannon Creek is the largest contributor of mine drainage to the West Branch Susquehanna River. During the survey period the stream contributed an average of about 65 tons/day net acidity to the West Branch. Stream quality at the mouth is fairly representative of stream quality throughout most of its length. Mean net acidity was 228 mg/l. Iron and manganese concentrations were 15.3 mg/l and 7.6 mg/l, respectively, during the survey period.

As in the Clearfield Creek basin, mining has been accomplished over most of the Moshannon Creek basin both by surface and subsurface methods. The quality of most of the streams in the watershed is influenced by mine drainage to some degree. A survey conducted in 1964 located 50 tributaries which were contributing acid to Moshannon Creek. The 10 streams listed in Table 4 are considered to be the most significant contributors of mine drainage. Figure 30 is a schematic representation of the principal mine drainage contributors to Moshannon Creek.

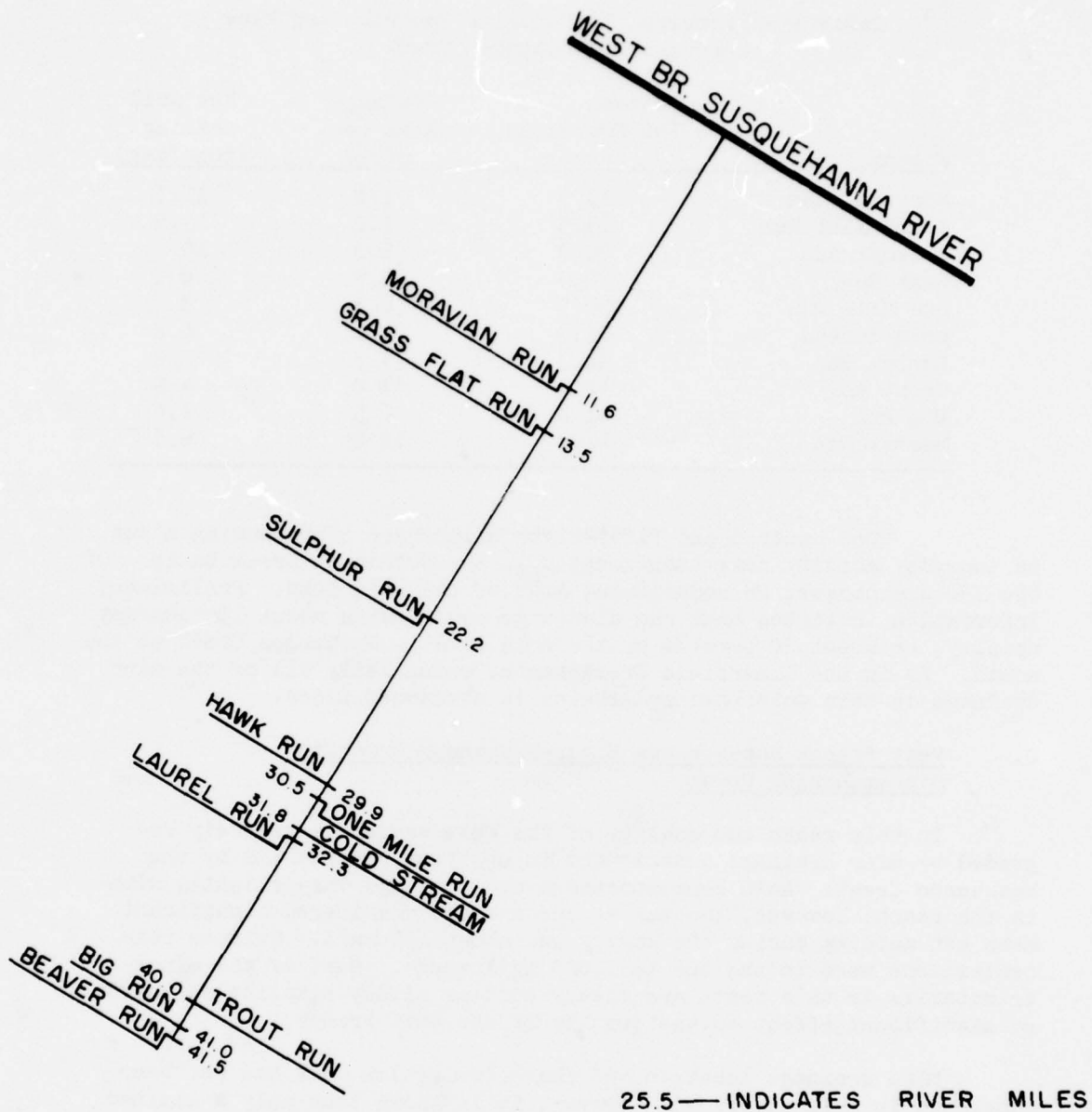


Figure 30. Schematic diagram of streams affected by coal mine drainage pollution in the Moshannon Creek Watershed.

Table 4 - Principal Tributaries Contributing Mine
Drainage to Moshannon Creek

Stream	Stream Mile (on Moshannon Creek)	Drainage Area (sq. mile)	Net Acid Loading (tons/day)
Moravian Run	11.6	1.8	11.5
Grass Flat Run	13.5	1.0	3.5
Sulphur Run	22.2	2.3	10
Hawk Run	29.9	2.4	8.2
One Mile Run	30.5	0.5	3
Cold Stream	31.8	23.6	6.2
Laurel Run	32.3	19.5	2.2
Trout Run	40.0	11.0	4.0
Big Run	41.0	2.5	1.6
Beaver Run	41.5	19.0	6.5

One hundred and fifty-eight discharges contributing about 68 tons/day acidity have been located in the Moshannon Creek basin. Of the 158 discharges, 26 contributed most of the acid load. Preliminary information indicates that one discharge contributes about 15 tons/day acidity, or about 20 percent of the acid load in Moshannon Creek at the mouth. As in the Clearfield Creek basin, essentially all of the mine drainage in this watershed originates in abandoned mines.

D. West Branch Susquehanna River-Moshannon Creek to
Sinnemahoning Creek

In this reach the quality of the West Branch is severely degraded by mine drainage contributed in upstream reaches and by the Moshannon Creek. Acid concentrations and loadings vary slightly within the reach; however, the variations are not considered significant. Mean net acidity during the survey was about 130 mg/l. Sulfate concentrations were in the 800 to 1,000 mg/l range. Most of the minor tributaries to this reach are mildly acid or mildly alkaline and have no significant effect on the quality of the West Branch.

Mine drainage location and characterization work has not been completed in this watershed; however, it is known that only a limited amount of mining has been accomplished and that acid drainage originates in abandoned underground mines.

1. Sinnemahoning Creek

During the study period Sinnemahoning Creek contributed about 18 tons/day net acidity to the West Branch. The creek, with its drainage

area of 1,032 square miles, has the largest watershed area tributary to the West Branch. It encompasses approximately 40 percent of the area of the West Branch basin at their confluence. Major tributaries include the First Fork, Bennett Branch, and Driftwood Branch. Although the stream has a large watershed area, topographic and geologic conditions combine to produce "flashy" flow characteristics with low drought flows and low natural alkalinity reserves in the stream. These characteristics combine to give it a very poor capacity to assimilate mine drainage discharges.

Although most of the watershed lies within the bituminous coal fields, mining activity has been restricted almost exclusively to the watersheds of the Bennett Branch Sinnemahoning and Sterling Run, a minor tributary to the Driftwood Branch Sinnemahoning. The Bennett Branch is essentially acid from its source to its mouth. It, in turn, renders Sinnemahoning Creek acid from their confluence to its mouth. Sterling Run, while not overcoming the alkalinity reserve in the Driftwood Branch, does add mine drainage indicators.

Although quite acid (136 mg/l net acidity), the Bennett Branch was found to contain relatively lower concentrations of other mine drainage indicators. The mean total iron and manganese concentrations were, for example, 1 mg/l, and 4.1 mg/l, respectively, during the survey period. Concentrations of most mine drainage indicators at the mouth of Sinnemahoning Creek are about half of Bennett Branch concentrations, reflecting the diluting effect of other tributaries of Sinnemahoning Creek.

A total of 100 discharges have been located in the Bennett Branch watershed, most of which originate in abandoned underground mines. Nine underground mine discharges contribute 12 tons/day of acidity, more than 65 percent of the total contributed by the 100 discharges.

E. West Branch Susquehanna River-Sinnemahoning Creek to Mouth

As shown in Figure 27, the quality of the West Branch in this reach changes significantly in response to several major influences, but particularly in response to the influence of Bald Eagle Creek.

Acid contributed by Sinnemahoning Creek was responsible for a 7.5 tons/day net acidity increase in the acid load in the West Branch below the creek mouth during the survey period. The contribution of an additional 7.5 tons/day acidity by Kettle Creek further increased the acid loading in the West Branch below that tributary. Although acid concentrations do not vary appreciably between Kettle Creek and North

Bald Eagle Creek, net acidity loadings increase with increases in flow at successive sampling stations. The apparent increase in loading is believed to be primarily the result of limitations in the precision of analysis and flow measurement procedures, and not to mine drainage discharges in the reach.

At Lock Haven (mile 68), North Bald Eagle Creek, with its contribution of 66 tons/day net alkalinity during the survey period enters the West Branch and contributes most of the alkalinity required to neutralize the acid load in the West Branch. Other major alkaline tributaries in the reach between Lock Haven and Williamsport (mile 040) that contribute to the neutralization of the West Branch include Pine Creek, Larry's Creek, Lycoming Creek, and Antes Creek.

Downstream from Williamsport, the West Branch is normally weakly alkaline (10 mg/l net alkalinity) and receives no direct mine drainage discharges. During unusual flow conditions, when the ratio of the flow in the West Branch to the flow in North Bald Eagle Creek is considerably higher than normal, the acid load carried by the West Branch is not neutralized, and acid conditions prevail downstream from Williamsport, sometimes to the mouth of the West Branch. This condition frequently occurs in late summer in conjunction with heavy rains in the Clearfield and Moshannon Creek watersheds with no corresponding rainfall in the North Bald Eagle Creek watershed. The condition, normally a once-yearly occurrence, causes extensive fish kills downstream from Williamsport.

1. Kettle Creek

Kettle Creek, with its contribution of 7.5 tons/day acidity during the survey period, is the most downstream direct source of mine drainage to the West Branch. Throughout most of its length, Kettle Creek flows through heavily forested land and is considered an excellent trout stream. In its lower 2 miles, its naturally low alkalinity is overcome by mine drainage contributed by Two Mile Run and discharges that enter directly.

2. North Bald Eagle Creek

North Bald Eagle Creek is responsible for neutralizing most of the acid load in the West Branch. Its contribution of 66 tons/day alkalinity during the survey period was the largest single source of alkalinity to the West Branch.

Considerable mining has taken place in the North Bald Eagle Creek drainage basin, however, and the quality of the lower reaches

of the stream is influenced by mine drainage. Essentially all the mining in the basin has been accomplished in the watershed of Beech Creek, a major tributary. Beech Creek is acid from its source to its mouth and contributed about 5 tons/day net acidity to North Bald Eagle Creek during the survey period. Under most natural flow conditions, the alkalinity in North Bald Eagle Creek is adequate to neutralize the acid contributed by Beech Creek. During periods of unbalanced rainfall and runoff in the basin, high flows from Beech Creek have significantly reduced the alkalinity in North Bald Eagle Creek. Flow regulation by Blanchard Dam, a multi-purpose structure now under construction immediately upstream from Beech Creek, may tend to accentuate this condition.

Mining conditions in the Beech Creek watershed are very similar to those in the nearby Clearfield and Moshannon Creek watersheds. Much of the watershed has been mined, both by surface and underground methods. Although more than a hundred mine drainage discharges have been located in the watershed, preliminary evaluation of the data indicates that most of the acid originates in six major discharges.

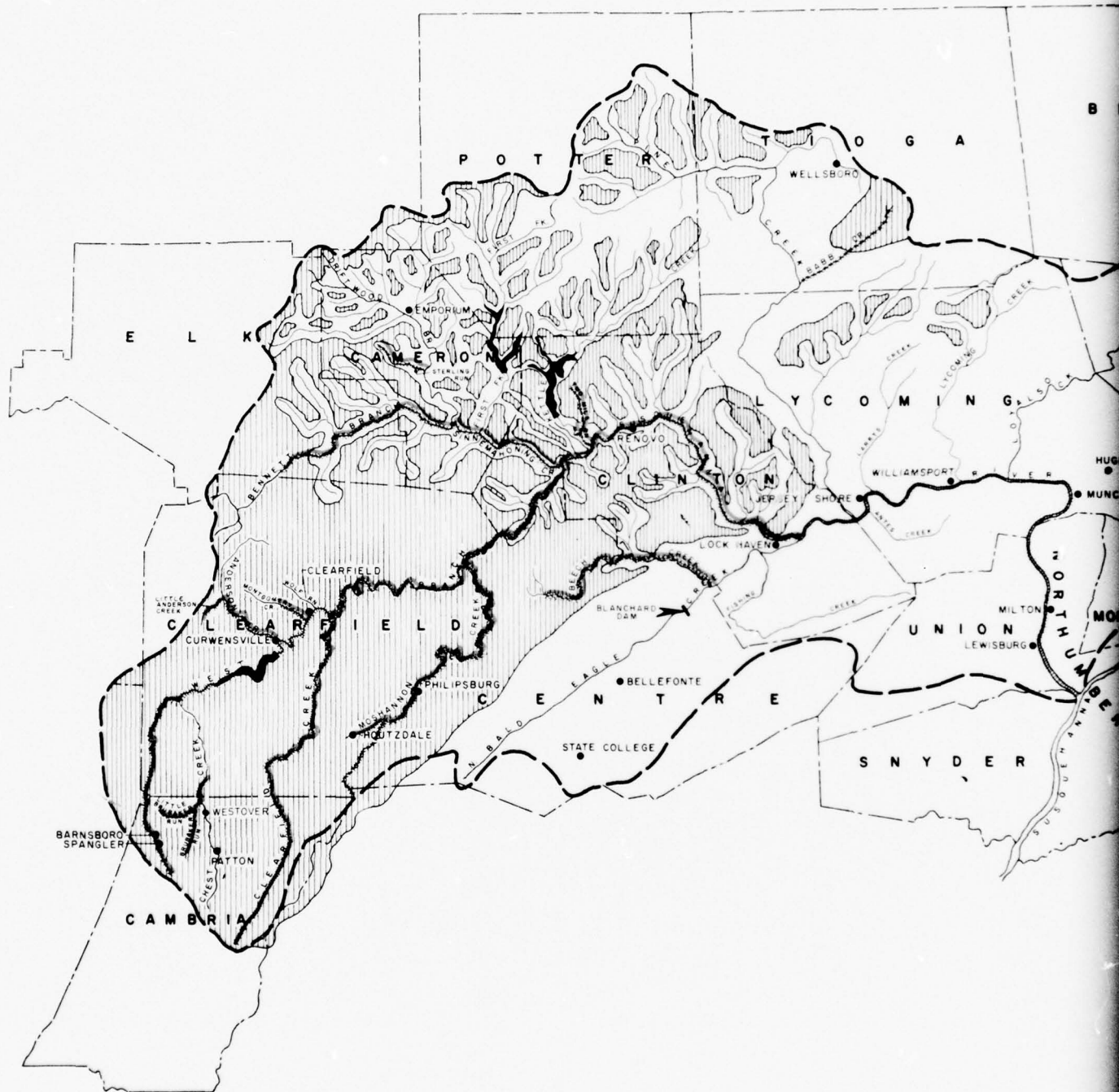
3. Pine Creek

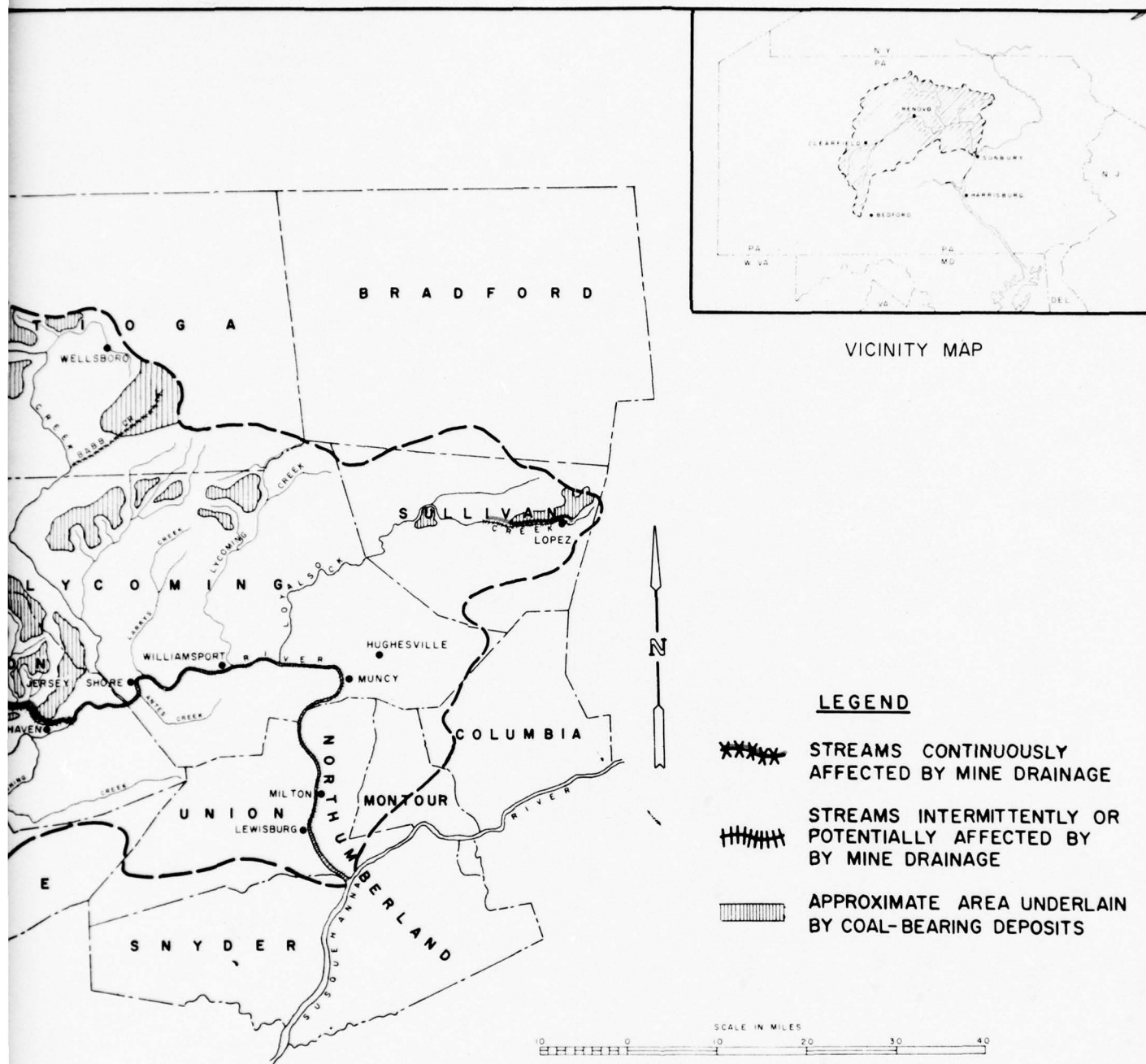
In the Pine Creek watershed, intense mining activity in the headwaters of Babb Creek (Fig. 25) has produced drainage which degrades the quality of Babb Creek throughout its length. Twenty-eight discharges have been located in the watershed, but six discharges are responsible for three-quarters of the total net acidity contribution of 7.5 tons/day. Babb Creek is slightly acid at its mouth, but it has no significant effect on Pine Creek which contributes an alkaline load to the West Branch Susquehanna River.

4. Loyalsock Creek

Although Loyalsock Creek is an alkaline stream at its mouth and bears no significant evidence of mine drainage indicators throughout most of its length, it does receive mine drainage from abandoned mines in an isolated semianthracite deposit in the headwaters.

Two drainage tunnels near the Village of Lopez (see Figure 25) discharge mine drainage with a net acidity concentration of approximately 60 mg/l. The addition of this slightly acid discharge to the stream, which has a naturally low residual alkalinity, causes degradation for approximately eight miles downstream.





APPALACHIA MINE DRAINAGE POLLUTION
REPORT

Figure 25

WEST BRANCH
SUSQUEHANNA RIVER BASIN

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

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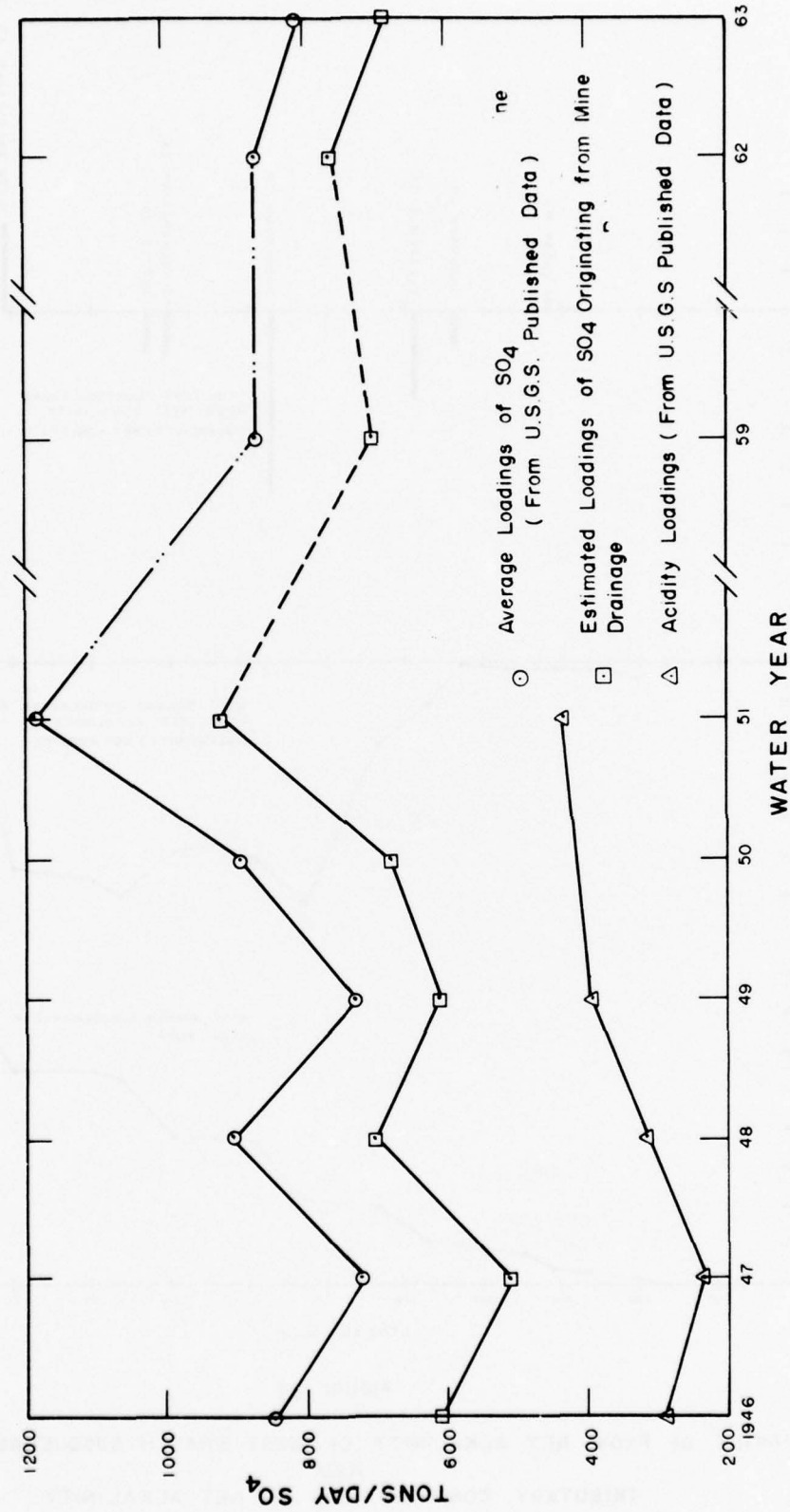


Figure 26: Average loads of acidity, total sulfate and sulfite considered to originate from coal mine drainage carried by the West Branch Susquehanna River at Lock Haven, Pennsylvania.

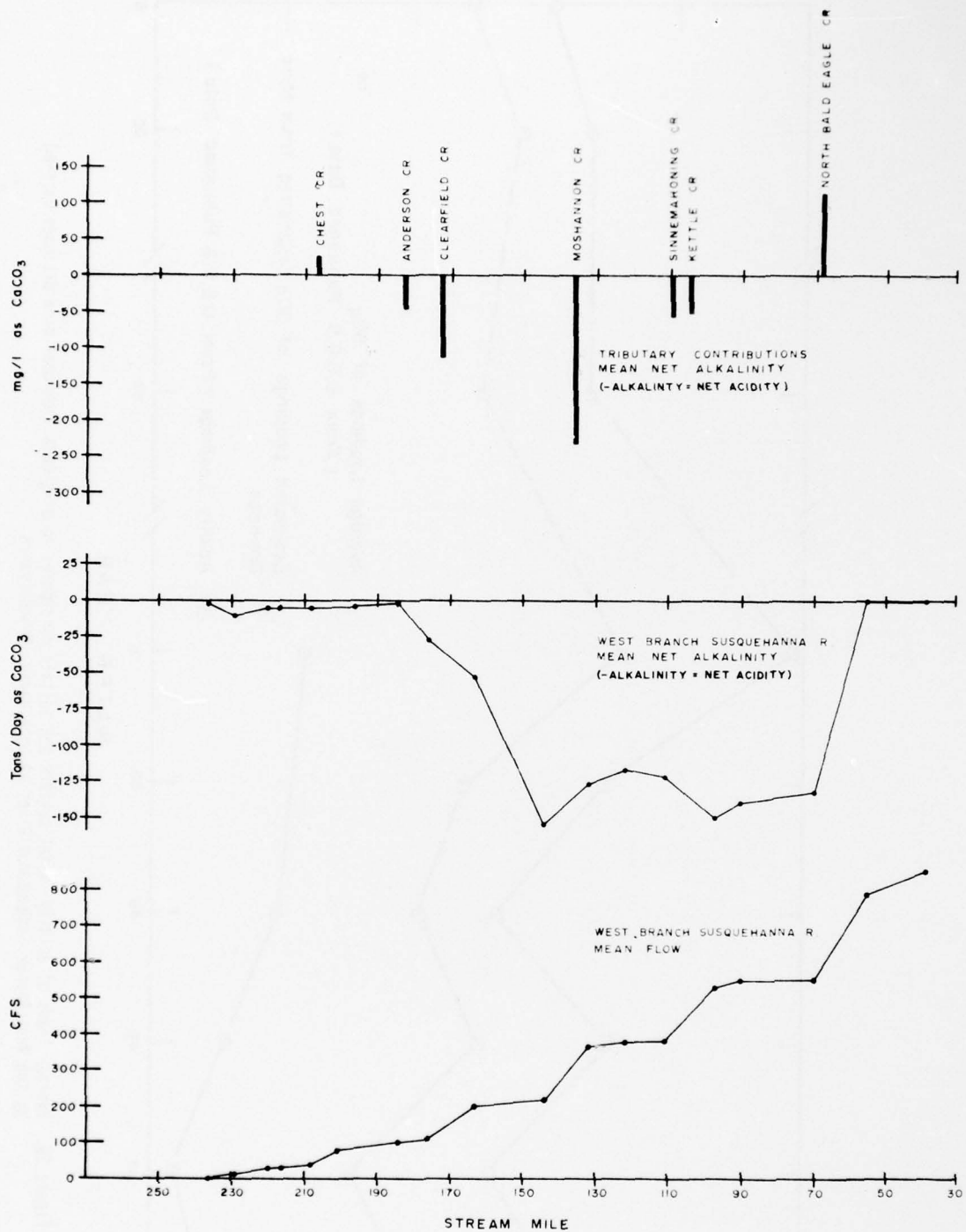


FIGURE 27

PROFILE OF FLOW, NET ALKALINITY OF WEST BRANCH SUSQUEHANNA RIVER
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

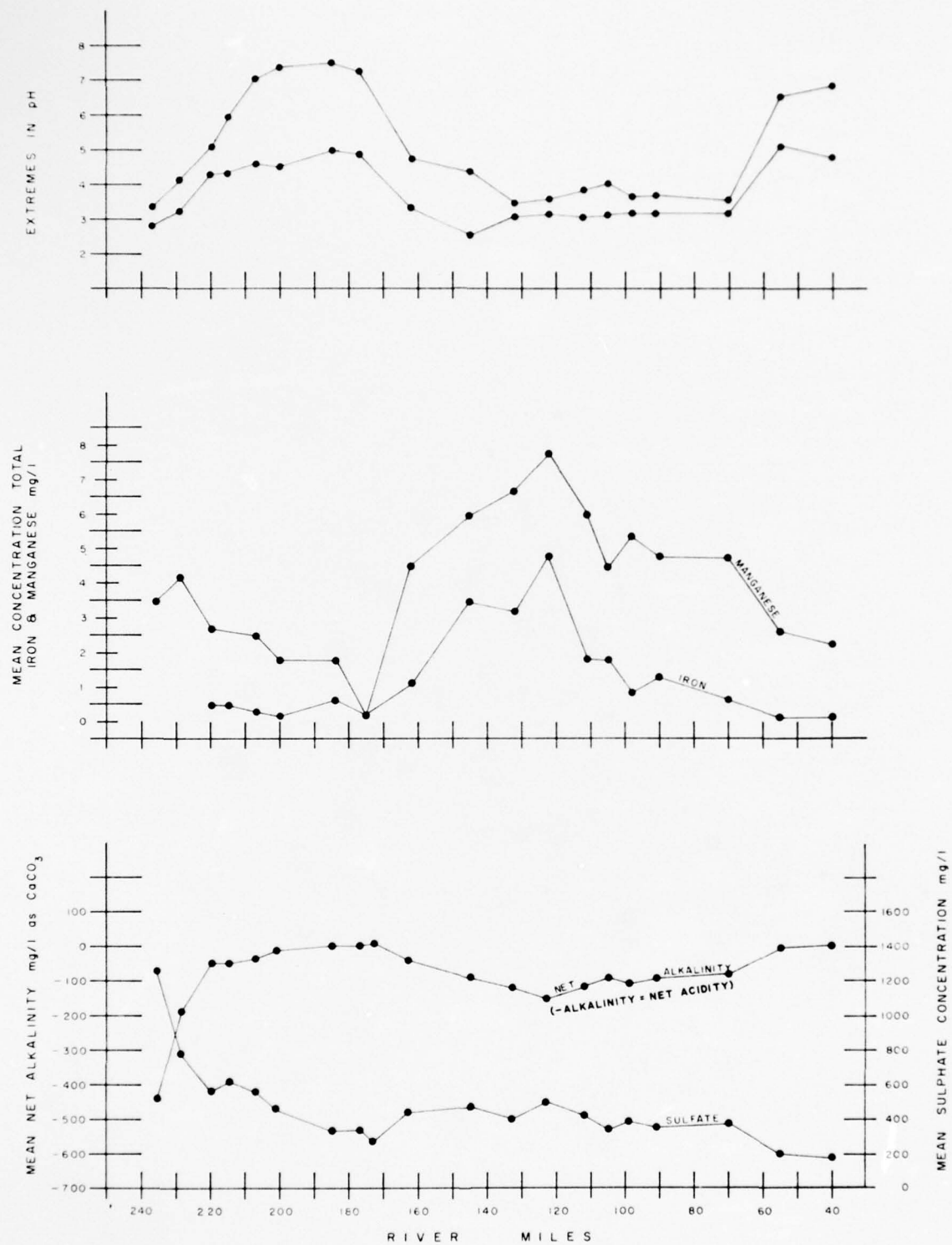


FIGURE 28 PROFILE OF pH, MANGANESE, IRON & SULFATE
CONCENTRATION AND NET ALKALINITY
WEST BRANCH, SUSQUEHANNA RIVER

Juniata River Basin

Description

The Juniata River, 86 miles long with a drainage area of 3,406 square miles, is formed by the junction of the Little Juniata River and Frankstown Branch Juniata River at Huntingdon, Pennsylvania. The stream flows easterly by a circuitous route to its confluence with the Susquehanna River (see Figure 31).

Virtually the entire Juniata River basin lies within the Valley and Ridge Province. This area is characterized by an alternate succession of long ridges and valleys, that trend generally southwest-northeast. The ridges in the western part of the basin are steep and rugged, whereas, the eastern part is considerably more rolling in nature. A small area on the western edge of the basin drains a part of the Appalachian Plateau Province. Elevations range from 340 to 2,900 feet above sea level.

The coal fields influencing stream quality are located in the southwestern portion of the watershed. The largest coal deposit in the watershed is the Broad Top coal field, located in Bedford, Huntingdon, and Fulton Counties. The field, approximately 81 square miles in area, lies in a highly dissected plateau known as Broad Top Mountain and is east of the Allegheny Mountains, totally isolated from the main bituminous coal fields.

A small portion of the main bituminous coal field lies within the watershed on the western edge of Blair County along the eastern slope of Allegheny Mountains.

The first authenticated record of coal mining in the area occurred during the Revolutionary War. The first commercial shipments were made in 1853, reaching a peak production of approximately 2.7 million tons in 1918. By 1964 coal production had diminished to about 0.4 million tons.

Projections of production in the Juniata basin are as follows (Wessel and others, 1964):

Projected Bituminous Production (Thousand Tons)

<u>1970</u>	<u>1985</u>	<u>2020</u>
490	780	1,520

Reserves of coal have been estimated to total 215 million tons of which approximately 129 million tons are recoverable (Wessel, 1966).

Mine Drainage Sources and Their Effect on Stream Quality

About 44 significant mine drainage sources that contribute about 19 tons/day of acidity exist in the Juniata River basin, all of which originate in abandoned underground mines. The drainage from these sources is causing continuous significant degradation of 60 miles of streams and intermittent significant degradation of 20 miles of streams.

The average loadings of sulfate in the Frankstown and Raystown Branches of the Juniata River in the years for which data are available were 87 tons/day and 70 tons/day, respectively. Of these sulfate loads 32 tons/day in the Frankstown Branch and 28 tons/day in the Raystown Branch are considered to have resulted from mine drainage acidity, indicating a total of about 60 tons/day of acidity formed in the Juniata basin. It is estimated that 19 tons/day of unneutralized acidity enters streams in the basin.

A. Little Juniata River

Mining activity in this basin has been limited almost exclusively to the Bells Gap Run watershed which has been extensively deep and strip mined.

Sampling of the Little Juniata River upstream from the confluence with Bells Gap Run (Figure 31) indicated an initial net alkalinity of 100 mg/l accompanied by low level concentrations of other mine drainage indicators. Bells Gap Run, despite mine drainage contributions, exhibits very little evidence of mine drainage indicators at its mouth and contributes an alkaline loading of approximately 170 lbs/day to the Little Juniata River.

B. Frankstown Branch Juniata River

The Frankstown Branch exhibited an alkaline reserve of 110 mg/l net alkalinity at its confluence with the Little Juniata during the sampling period. The stream, while alkaline, contains significant levels of iron and hardness, mine drainage indicators.

The major contributor of mine drainage during the sampling period was the Beaver Dam Branch, which contributed approximately 1.5 tons/day net acidity. The major sources of mine drainage to the Beaver Dam Branch were Burgoon Run and Sugar Run.

Burgoon Run receives mine drainage from Kittanning Run and Glenwhite Run, small streams whose watersheds have been almost completely

disturbed by surface mining. Kittanning Run is diverted around a public water supply reservoir serving the city of Altoona and enters Burgoon Run downstream from the reservoir. The flow of the upper reaches of Burgoon Run and the normal flow of Glenwhite Run form the reservoir supply. During periods of high runoff, however, the flow of Glenwhite Run is also diverted to the by-pass.

Sugar Run had an acid loading at its mouth of 0.5 tons/day net acidity. Most of the acid originates in the discharge from one abandoned deep mine.

C. Raystown Branch Juniata River

Mine drainage in this drainage basin originates in the Broad Top Coal Field and is conveyed to the Raystown Branch by Longs Run, Six Mile Run, Shoups Run, and Great Trough Creek. Each of the first three streams is acid from its source to its mouth. Great Trough Creek is acid through its length in the coal fields, approximately five miles. Alkaline tributaries neutralize the acid load and provide an alkaline reserve at its mouth.

The three acid streams contributed the following acid loading to the Raystown Branch during the survey period:

Longs Run, 2.5 tons/day net acidity
Six Mile Run, 1.4 tons/day net acidity
Shoups Run, 1.6 tons/day net acidity

In spite of the sizable acid contributions, as shown in Figure 32, the alkaline reserve of Raystown Branch upstream (21 tons/day during the sampling period) was more than ample to assimilate the acid contributed. The Raystown Branch downstream from the coal field exhibited essentially no evidence of the mine drainage loading.

Water quality in the three acid streams was generally comparable. They had pH values of less than 4.5, and elevated concentrations of manganese, sulfate, hardness, and other mine drainage indicators. Inexplicable, the iron concentration in Shoups Run was normally less than 1 mg/l; while in Longs Run and Six Mile Run, mean concentrations exceeded 10 mg/l.

Almost all of the mine drainage discharges located in the watersheds tributary to the Raystown Branch originated in deep mines. A limited amount of surface mining has taken place in the basin and may be influencing deep mine discharges; however, no surface discharges were observed.

D. Aughwick Creek

A small percentage of the Broad Top coal fields lies in the Aughwick Creek basin. Roaring Run, a tributary of Sidling Hill Creek, which in turn is tributary to Aughwick Creek, is the only known contributor of mine drainage in the basin. Roaring Run with its acid loading of 750 lbs/day during the sampling period degraded the quality of Sidling Hill Creek at their confluence. Alkalinity contributed by other tributaries enabled Sidling Hill Creek to recover from the acid loading and have an alkaline reserve at its mouth.

C E N T R E

CAMBRIA

BLAIR

HUNTINGDON

SOMERSET

BEDFORD

FULTON

FRANKLIN

TYRONE

ALTOONA

WILLIAMSBURG

MOUNT UNION

SAXTON

ROARING SPRING

HOLLIDAYSBURG

EVERETT

BEDFORD

LEWISTOWN

BELLEVILLE

JUNIATA RIVER

LITTLE JUNIATA RIVER

SUGAR RUN

BEAVER DAM BRANCH

ROARING RUN

SIDELING HILL

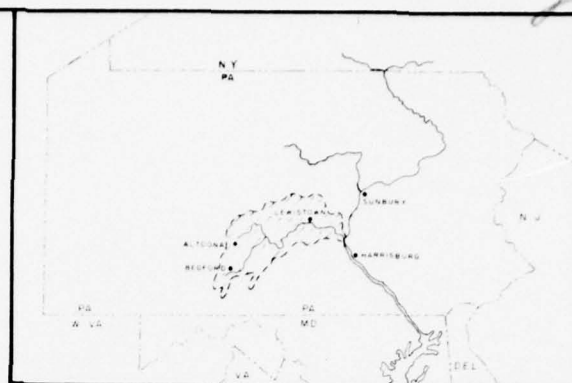
AUGWICK CREEK

TUSCARORA CREEK

STANDING STONE CREEK

PA

MD



VICINITY MAP



LEGEND



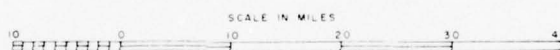
STREAMS CONTINUOUSLY
AFFECTED BY MINE DRAINAGE



STREAMS INTERMITTENTLY OR
POTENTIALLY AFFECTED BY
BY MINE DRAINAGE



APPROXIMATE AREA UNDERLAIN
BY COAL-BEARING DEPOSITS



APPALACHIA MINE DRAINAGE POLLUTION REPORT

Figure 31

JUNIATA RIVER BASIN

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

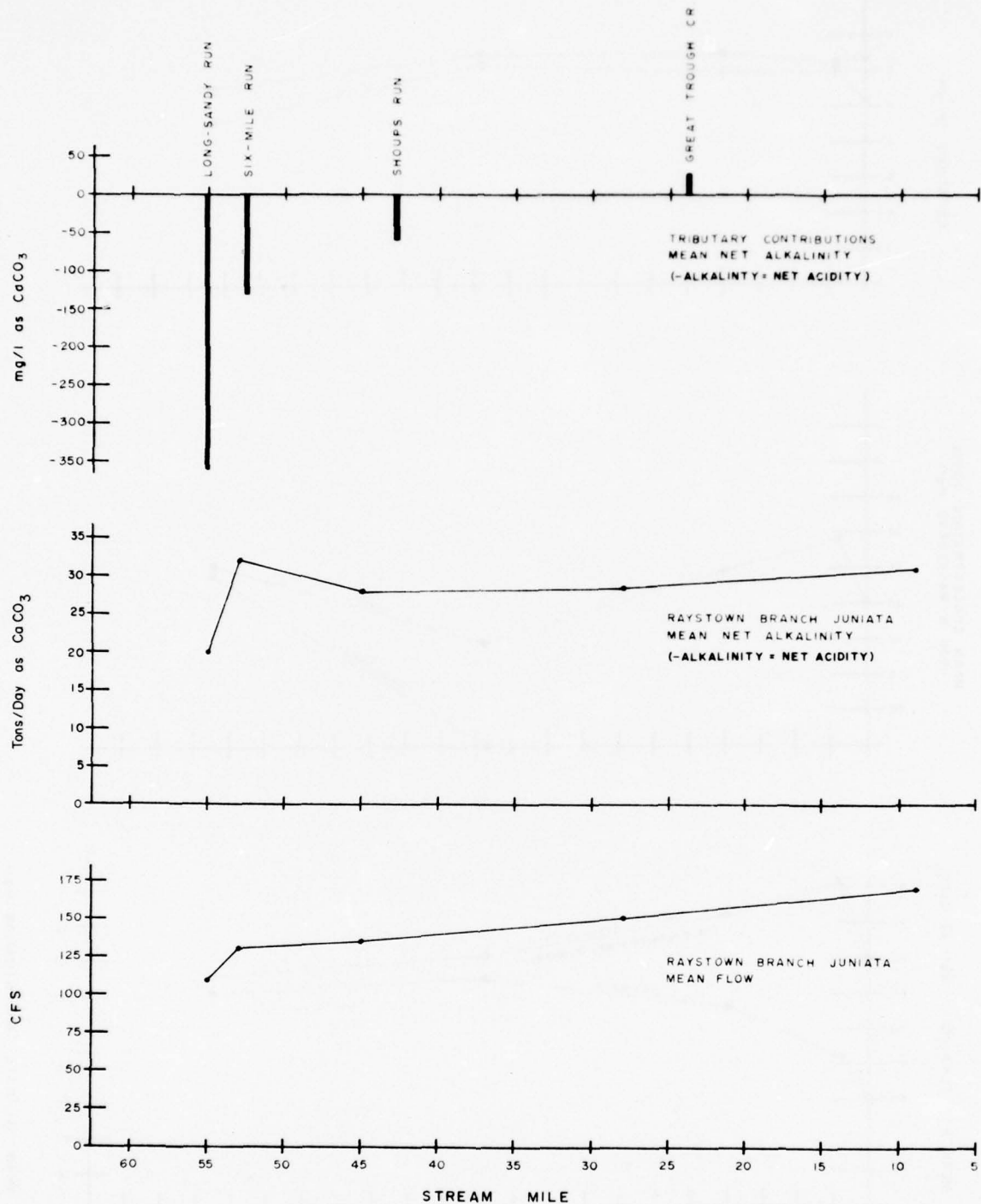


FIGURE 32
 PROFILE OF FLOW, NET ALKALINITY OF RAYSTOWN BRANCH JUNIATA RIVER
 AND
 TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

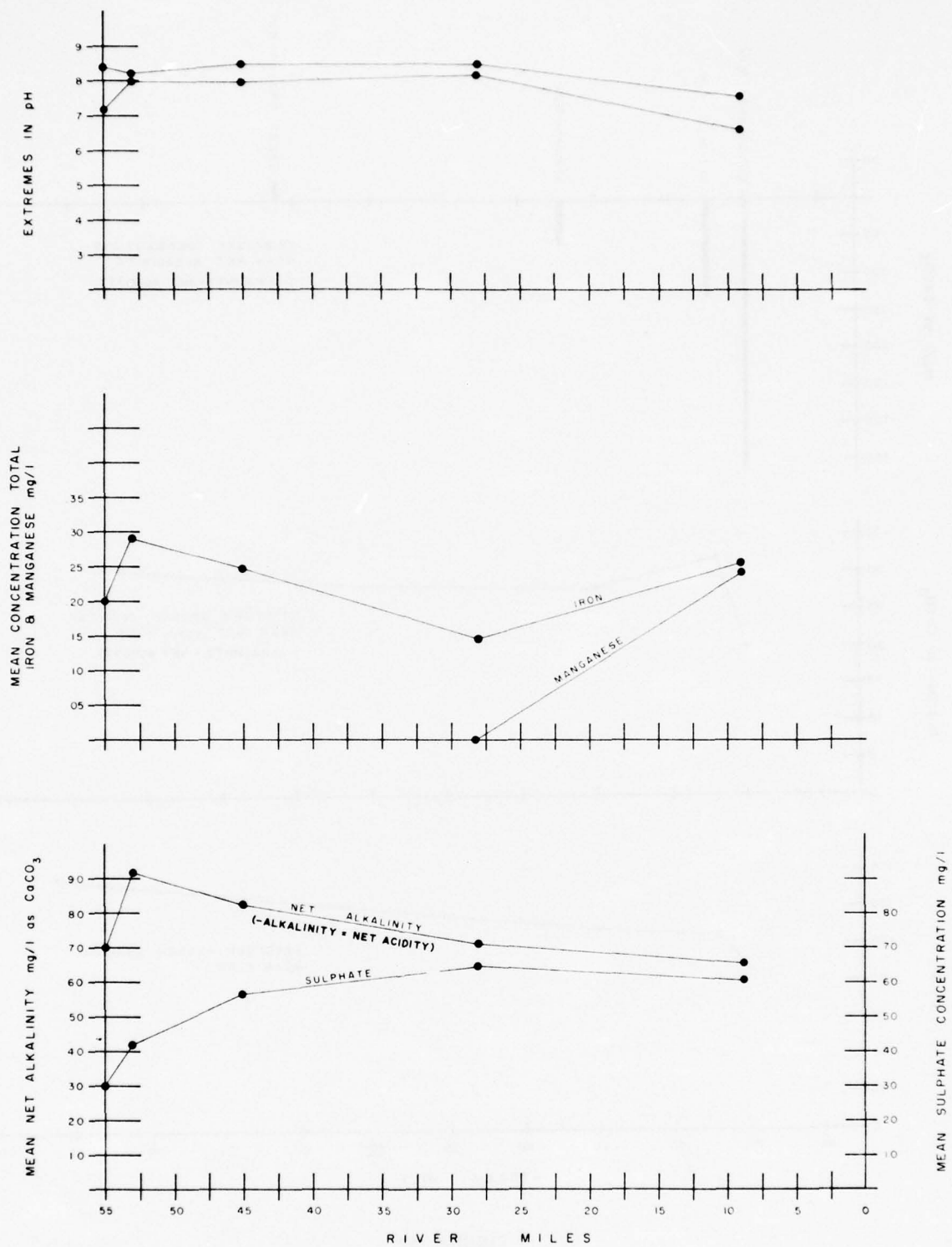


FIGURE 33 PROFILE OF pH, MANGANESE, IRON & SULFATE CONCENTRATION AND NET ALKALINITY
 RAYSTOWN BRANCH, JUNIATA RIVER

North Branch Potomac River

Description

The North Branch of the Potomac River rises in Tucker County, West Virginia, and flows alternately northeast and southeast in a zigzag pattern for about 98 miles until it meets the South Branch to form the Potomac River (Figure 34).

The North Branch forms the boundary between Maryland and West Virginia downstream from Kempton, Maryland. The North Branch is bounded on the Maryland side by Garrett and Allegheny Counties and on the West Virginia side by Grant, Mineral, and Hampshire Counties.

The coal-bearing area of the North Branch basin lies in a continuous trough-shaped valley about 80 miles long, oriented in a north-east-southwest direction. The North Branch flows northeast through the center of the basin for almost two-thirds of its length. The northeast part of the valley is drained by Georges Creek, which flows southwest through the center of the valley to join the North Branch at Westernport. The coal-bearing region southwest of Westernport is known as the Upper Potomac coal fields. The coal region drained by Georges Creek, Savage River, and two small tributaries of Wills Creek is known as the Georges Creek coal field. Coal is mined from the Pittsburgh, Tyson, Bakerstown, Waynesburg, Freeport, and Kittanning coal seams.

Coal has been mined in the North Branch basin for about 150 years. Maryland's peak production of coal occurred in 1907, earlier than any other major coal-producing state. Coal production in the North Branch basin for the 1961-1965 period was:

1961	- 1.0 million tons
1962	- 1.0 million tons
1963	- 1.3 million tons
1964	- 2.2 million tons
1965	- 3.3 million tons

About 2.2 million tons were mined in West Virginia (Upper Potomac Field) and 1.1 million tons in Maryland in 1965. The Upper Potomac field accounted for 85 percent of the 1965 North Branch basin coal production. In 1961 and 1962, Maryland accounted for about 75 percent of the coal produced in the North Branch basin; in 1965 Maryland accounted for only 33 percent.

Mine Drainage Sources and Their Effect on Stream Quality

During the sampling program conducted by the Chesapeake Bay-Susquehanna River Basins Project of the FWPCA in August and October 1966 and April 1967, the North Branch of the Potomac River was found to be acid as a result of coal mine drainage from its source to Luke, Maryland. Until recently, spent process lime discharged by the West Virginia Pulp and Paper Company's Luke Mill neutralized the acid contributed upstream; but the lime is no longer discharged and acid conditions will extend further downstream in the future. Sampling by the Maryland Department of Water Resources (MDWR) in April, July, and November 1966 and a period of continuous monitoring by MDWR in April 1967 revealed similar conditions. This report is based partly on the MDWR data. The data are the result of year-round sampling programs rather than low flow surveys. They do, however, represent water quality at below average and relatively uniform conditions.

From its source to the area of Westernport, Maryland, where it leaves the coal region, the North Branch receives acid mine drainage from at least eleven tributaries (see Figure 34). Of these tributaries, Elk Run, Laurel Run, and Abram Creek contributed 65 percent of the total measured net acidity load of 33 tons/day in the North Branch basin. The total mine drainage acidity formed in the basin is estimated to be 70 tons/day based on sulfate loadings measured during 1966-1967.

Eighty-one percent of the total net acidity measured in the stream originated in the Upper Potomac coal field, 2 percent in the Georges Creek field, and 17 percent was unaccounted. Fifty-seven percent of the total measured net acidity originated in the headwaters above the USGS gage at Steyer, Maryland. West Virginia sources contributed 63 percent of the total measured acid load in the North Branch basin. Maryland tributaries added 20 percent.

Based on data from the Maryland Department of Water Resources (1965) and a knowledge of the area, it is estimated that there are in the order of 630 sources of mine drainage in the North Branch basin. There are 469 sources in Maryland alone, including 400 in inactive mines and 69 in active mines (Maryland Department of Water Resources, 1965)

In 1966, a total of 130 miles of stream in the North Branch basin was continuously polluted by mine drainage, and an additional 30 to 40 miles were mildly or intermittently affected. Most of these streams carried a net acid load. There are few sources of natural

alkalinity in the region. Shales and sandstones containing coals and fire clays dominate the geology. There is only one limestone stratum in the North Branch basin, and that lies in the Georges Creek watershed.

Biological sampling throughout the North Branch basin revealed, in general, only sparse populations of acid-tolerant benthic organisms. There conditions are attributed to mine drainage pollution.

A detailed discussion of the mine drainage sources in the North Branch basin and their effect on stream quality follows:

A. North Branch Headwaters at Steyer, Maryland

The North Branch was sampled at Kempton, Maryland, approximately two miles downstream from its source. As shown in Figure 35, at Kempton the North Branch discharged 0.2 tons/day net acidity, less than 1 percent of the net acidity contributed in the basin. Fourteen miles downstream from Kempton, at Steyer, Maryland, the net acidity load had increased to 26 tons/day. The acidity measured at Steyer was 82 percent of the total net acidity measured in the North Branch. The three tributaries discussed below discharged 18 tons/day to the North Branch in this reach.

1. Elk Run

Elk Run, a minor tributary in terms of drainage area, contributes more net acidity to the North Branch than any other tributary. At its confluence with the North Branch, Elk Run had a pH of 2.8 and a mean net acidity concentration of 1,900 mg/l. The measured flows ranged between 1.7 and 3.3 cfs, but the enormous acid concentration resulted in a mean contribution of 12 tons/day net acidity to the North Branch. This load represents 38 percent of the total measured net acidity in the North Branch. Elk Run's streambed was colored a bright orange, a purplish brick-red, and green (algae) and was covered with a crusted sediment more than a foot thick in many places. The Elk Run sampling stations lies a few hundred yards downstream from a coalyard and mines operated by the Alpine Coal Company.

Three water samples collected at the same site by the West Virginia Division of Water Resources indicated that acid concentrations were roughly an order of magnitude lower than present concentrations as mining operations.

2. Laurel Run

Laurel Run discharged 4.9 tons/day net acidity to the North Branch, 14 percent of the total measured net acid load. Although there are strip mines in the watershed, most of the mine drainage originates

in an abandoned underground mine near Kempton. Much of the mine is in West Virginia.

3. Buffalo Creek

Buffalo Creek discharged 1.5 tons/day net acidity to the North Branch, 5 percent of the total measured net acid load in the North Branch basin. Samples were taken a few hundred feet above the confluence with the North Branch at Bayard, West Virginia. The North Branch Coal Company yard is located upstream.

B. North Branch - Steyer, Maryland, to Kitzmiller, Maryland

Thirteen miles downstream from Steyer, at Kitzmiller, Maryland, the acid load in the North Branch was 32 tons/day net acidity, an increase of 6 tons/day over the load at Steyer. The acid load at Kitzmiller equals the total net acidity measured in the North Branch. Below Kitzmiller the net acidity contributions are small and are balanced by natural contributions of net alkalinity. The three tributaries discharging net acidity to the North Branch in this reach are: Stony River (0.8 tons/day), Wolfden Run (0.1 ton/day), and Abram Creek (4.2 ton/day).

1. Stony River

The quality of Stony River is very mildly influenced by mine drainage near Mount Storm, West Virginia, about 5 miles above its confluence with the North Branch. At Mount Storm the river supports trout. The only known contribution of mine drainage to Stony River is from Laurel Run, a small intermittently polluted tributary several miles upstream.

2. Abram Creek

The 4.2 tons/day acidity contributed to the North Branch by Abram Creek is 13 percent of the total measured net acidity in the North Branch basin. The major part of the mine drainage in Abram Creek originates in the headwaters at Bismark, West Virginia. The net acidity load at this point was 1.9 tons/day. Downstream, at Mt. Pisgah, West Virginia, Abram Creek carried 4.5 tons/day net acidity, a load substantially equal to that discharged to the North Branch. Two tributaries, Glade Run and Emory Creek, discharged an estimated total of 1 ton/day net acidity below Mt. Pisgah, but some neutralization occurs before the water reaches the North Branch.

C. North Branch - Kitzmiller, Maryland, to the Savage River

Just above the mouth of the Savage River, fourteen miles downstream from Kitzmiller, Maryland, the North Branch carried 31 tons/day net acidity, a decrease from the acidity loading at Kitzmiller. Measured contributions of net acidity in the Kitzmiller-Savage River reach amounted to 2 tons/day, indicating that neutralization occurs in this reach. The North Branch is grossly polluted at Kitzmiller. Measured pH values were less than 3.5 and benthic sampling revealed no organisms. The four tributaries discharging net acidity to the North Branch between Kitzmiller and the Savage River are:

1. Three Forks Run

Three Forks Run discharged 1.0 tons/day net acidity to the North Branch, 3 percent of the total measured net acidity load in the North Branch basin. It is grossly polluted by runoff from mines and possibly from spoil piles in the watershed. In August 1966, a pH of 1.8 was measured in Three Forks Run.

2. Deep Run

Deep Run discharged an insignificant net acidity load to the North Branch, less than 1 percent of the total measured net acidity in the North Branch basin. Benthic sampling indicated sparse populations of clean-water organisms. Deep Run is mildly polluted by mine drainage.

3. Elklick Run

Elklick Run was sampled once, during April 1967, just above its confluence with the North Branch. The stream lies in Maryland about a mile downstream from Shaw, West Virginia. Elklick Run contributed 0.3 tons/day net acidity to the North Branch, about 1 percent of the total measured load in the watershed.

4. Piney Swamp Run

Piney Swamp Run contributed 1.3 tons/day net acidity to the North Branch, or 4 percent of the total measured net acidity in the watershed. Samples were taken at Hampshire, West Virginia, a few hundred feet above the confluence with the North Branch. The Hampshire station lies at the foot of an active mining area operated by Masteller Coal Company. Above these operations, the flow in Piney Swamp Run is only about 15 percent of the flow at the mouth and stream quality is considerably better than at Hampshire.

D. North Branch - Savage River to Cumberland, Maryland

The acidity loading of 31 tons/day carried by the North Branch just above the mouth of the Savage River augmented slightly by acidity discharged from Georges Creek, but alkalinity contributed by the West Virginia Pulp and Paper Company Mill at Luke, by the Upper Potomac River Commission Waste Treatment Plant at Westernport, and by other sources largely neutralizes the acidity in the North Branch. This neutralization is reflected by the increase in average pH from about 4.0 just above the mouth of the Savage River to about 6.5 at Keyser 7-1/2 miles downstream.

No mine drainage acidity enters the North Branch below Georges Creek, but some mine drainage pollution is discharged into the North Branch by Wills Creek at Cumberland in the form of hardness and sulfates. Tributary and mill effects are discussed below in the order in which they occur:

1. Savage River

The quality of the Savage River is mildly degraded by mine drainage in a one-mile reach from its mouth to Aaron Run. In this reach, Savage River maintains about 5 mg/l net alkalinity. This results in a discharge of 0.8 tons/day net alkalinity, which is not adequate to appreciably reduce the net acidity load in the North Branch although some reduction in acid concentration occurs by dilution. The Savage River is regulated to maintain a minimum flow of 93 cfs in the North Branch at Luke. Aaron Run, the only contributor of mine drainage to Savage River, is badly polluted. Upstream from Aaron Run, the water in Savage River is of excellent quality.

2. West Virginia Pulp and Paper Company

Until recently, spent process lime discharged from the West Virginia Pulp and Paper Company Mill at Luke neutralized the acid load in the North Branch. Since late 1966 this spent lime has been reprocessed within the plant. As a result, the acidity that originates upstream from the mill is no longer completely neutralized.

The company withdraws more than 20 mgd of process water from the North Branch at Luke. This reduces the acid load by about 8 tons/day or about 25 percent. Waste is returned downstream at Westernport, except for boiler house, evaporator, and flyash discharges at Luke. These discharges have some neutralizing effect, but will be discontinued soon.

During April 1967, the Maryland Department of Water Resources monitored the pH of the North Branch below the West Virginia Pulp and Paper Company mill. The pH alternated between 3.5 and 4.5, depending presumably on intermittent discharges of alkaline waste. After the waste discharges are stopped, the pH will probably not rise above 4.0.

3. Georges Creek

Georges Creek, which enters the North Branch at Westernport, Maryland, contributes 0.6 tons/day net acidity, or 2 percent of the total measured net acidity in the North Branch basin. Most of the acidity in Georges Creek enters directly from deep mines that line the sides of the valley.

4. Upper Potomac River Commission Waste Treatment Facility

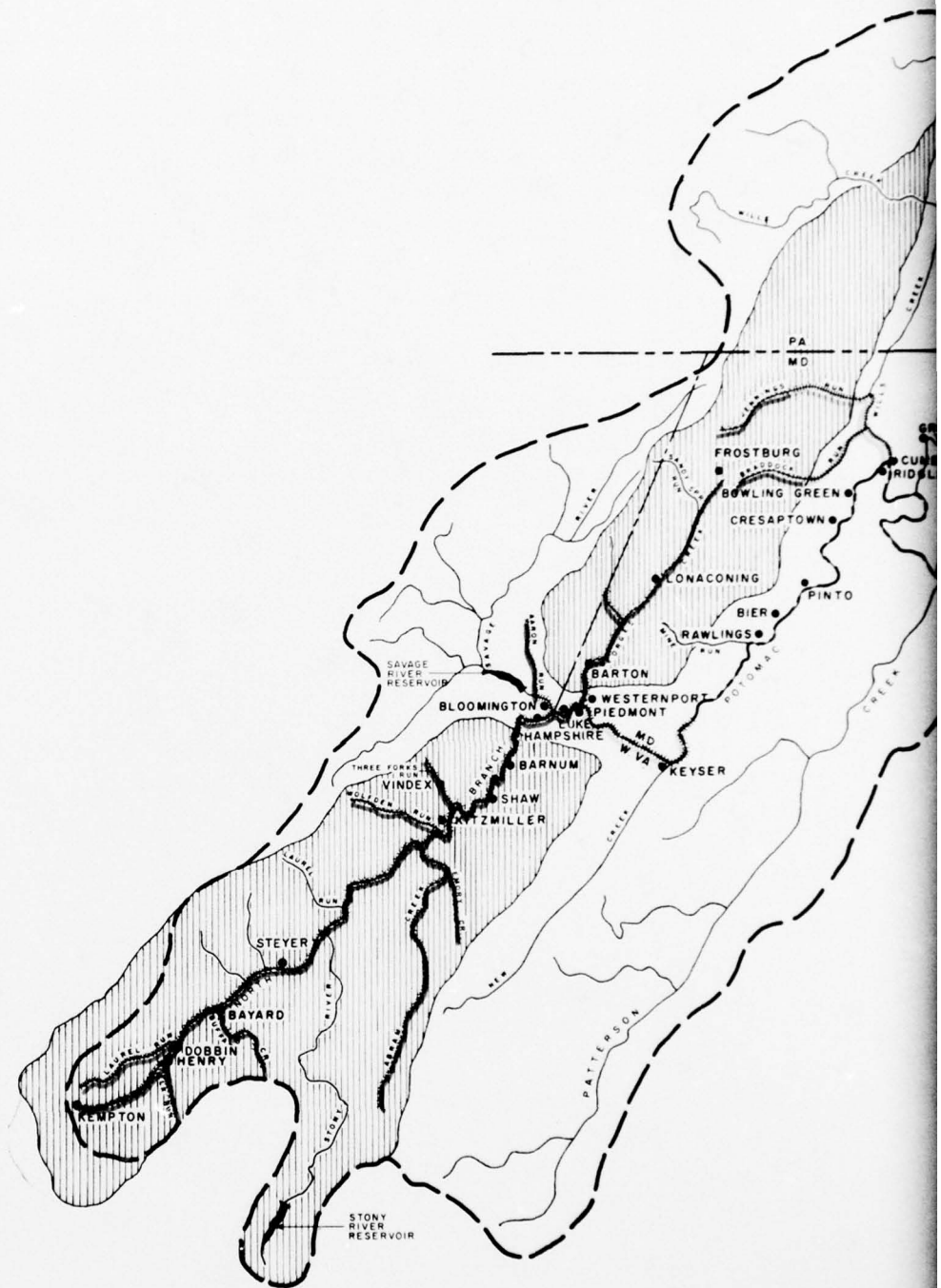
This waste treatment plant is located on the downstream side of Westernport, Maryland. About 95 percent of the plant's load consists of process wastes from the West Virginia Pulp and Paper Company Luke Mill. The UPRC plant discharges an average of 20 mgd, which contributes a load of 8.5 tons/day net alkalinity to the North Branch. This is equivalent to 27 percent of the total measured net acidity in the North Branch basin. Three miles downstream from the UPRC plant, at Keyser, West Virginia, pH values between 6 and 7 were observed in the North Branch early in 1967.

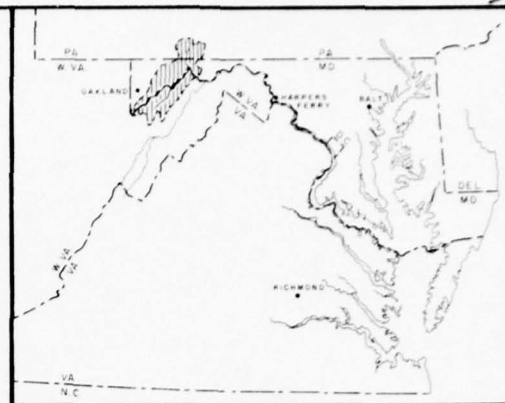
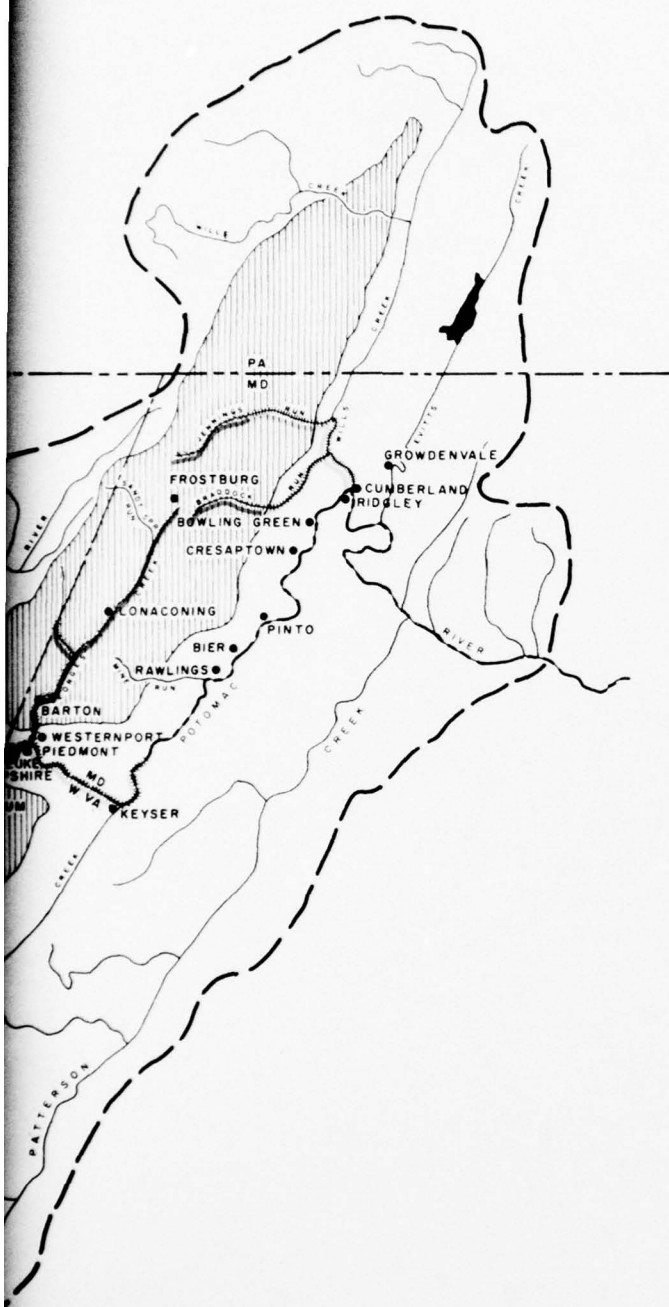
5. Wills Creek

Wills Creek, which enters the North Branch in downtown Cumberland, Maryland, does not contribute acidity to the North Branch, although mine drainage residual effects (high hardness and sulfate concentrations) are apparent in chemical data. Braddock Run and Jennings Run, tributaries that enter Wills Creek from the Georges Creek coal field to the west, are degraded by mine drainage. Braddock Run receives the discharge from the Hoffman Tunnel, a drainage tunnel bored in the early 1900's to drain deep mines in Georges Creek basin.

At Cumberland, Maryland, high hardness and sulfate concentrations are apparent in North Branch chemical data, but acid conditions have not been observed.

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VICINITY MAP

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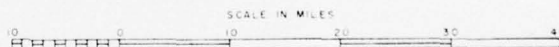
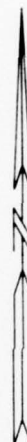
STREAMS CONTINUOUSLY
AFFECTED BY MINE DRAINAGE



STREAMS INTERMITTENTLY OR
POTENTIALLY AFFECTED BY
BY MINE DRAINAGE



APPROXIMATE AREA UNDERLAIN
BY COAL-BEARING DEPOSITS



APPALACHIA MINE DRAINAGE POLLUTION REPORT

Figure 34 NORTH BRANCH POTOMAC RIVER BASIN

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

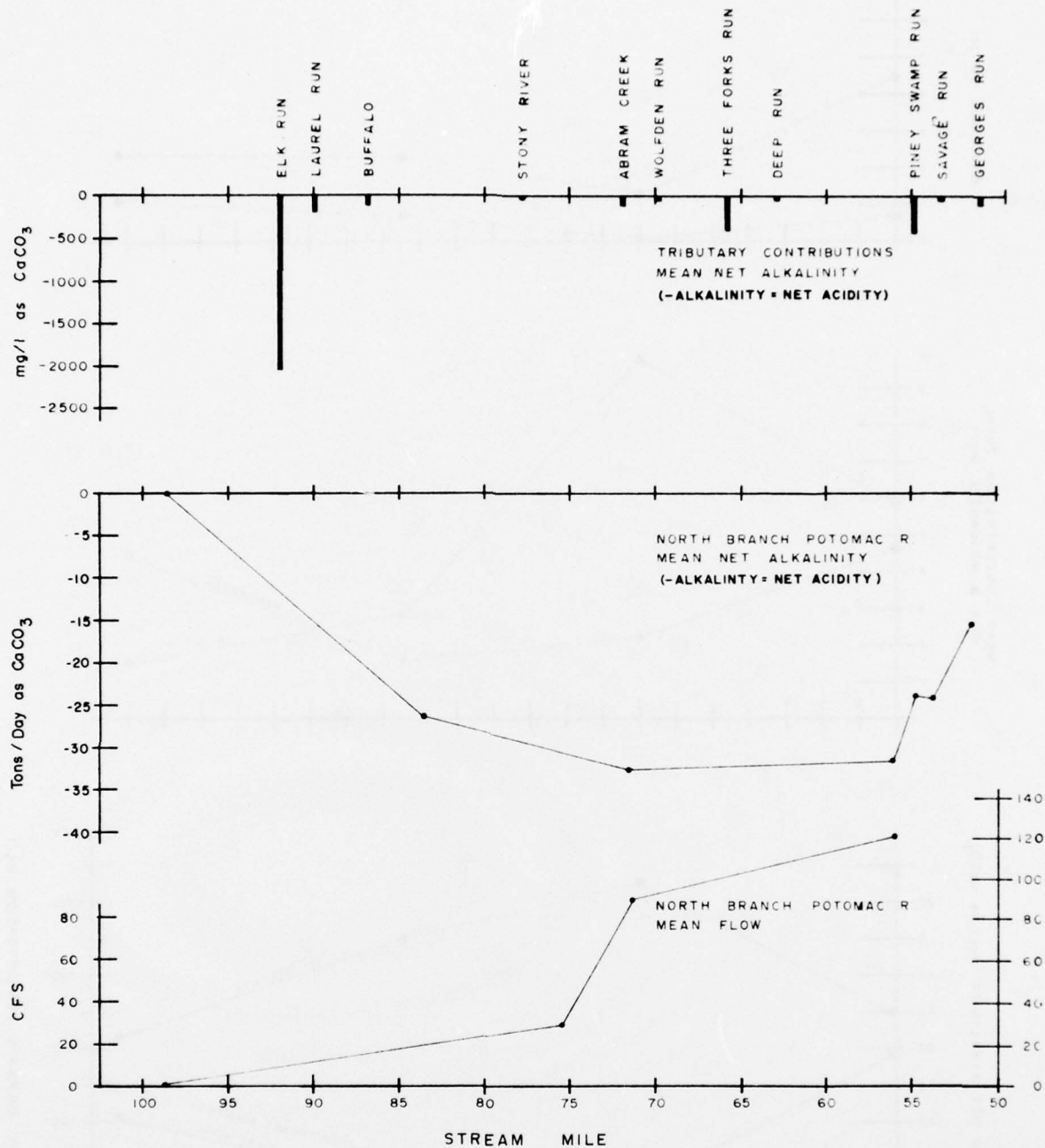


FIGURE 35
 PROFILE OF FLOW, NET ALKALINITY OF NORTH BRANCH POTOMAC RIVER
 AND
 TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

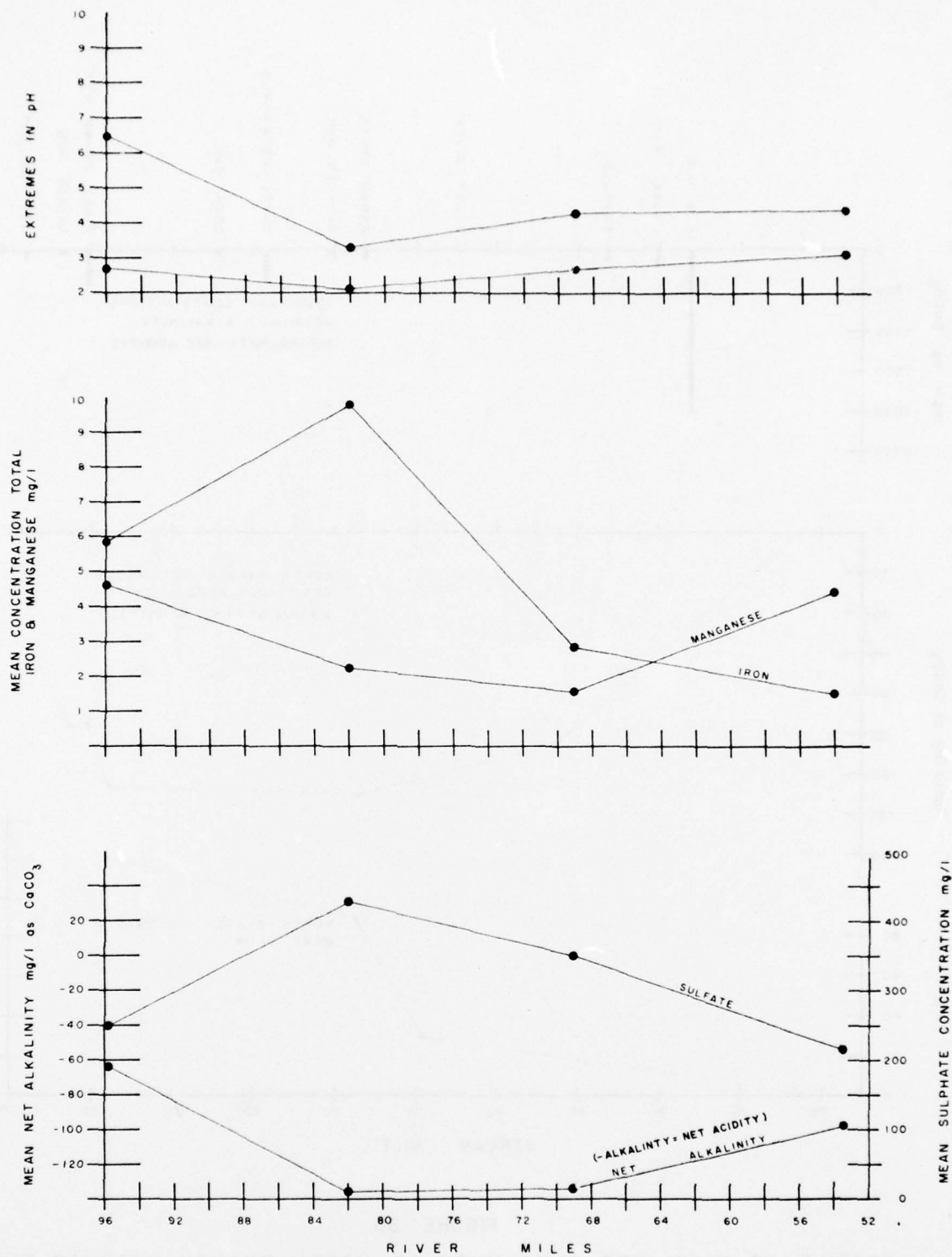


FIGURE 36 PROFILE OF pH, MANGANESE, IRON & SULFATE
 CONCENTRATION AND NET ALKALINITY
 NORTH BRANCH POTOMAC RIVER

Allegheny River Basin

Description

The Allegheny River rises near Coudersport in Potter County, Pennsylvania (Fig. 37). It flows westward and then northward into New York then turns south near Salamanca, New York, and flows south-westward through Pennsylvania. It joins the Monongahela River at Pittsburgh to form the Ohio River. The total length of the Allegheny River is about 325 miles.

The Allegheny River basin embraces about 11,730 square miles in western New York and Western Pennsylvania all of which is within the Appalachian Region. It is about 175 miles long on a north-south axis and its maximum width is about 130 miles. About 1,965 square miles of New York and 9,765 square miles of Pennsylvania are in the watershed. Adjacent are the Great Lakes-St. Lawrence River basin on the north, the Susquehanna River basin on the east, the Monongahela River basin on the south, and the Beaver River basin or direct drainage to the Ohio River on the west. Principal tributaries to the Allegheny are the Kiskiminetas and Clarion Rivers, and Mahoning, Redbank, French, Oil, Tionesta, and Conewango Creeks.

The Allegheny River basin is in the southern New York and Kanawha sections of the Appalachian Plateau's physiographic province. The southern New York section represents a mature glaciated plateau of moderate relief. The Kanawha section represents a mature unglaciated plateau of fine texture with moderate to strong relief.

About 25 percent of the topography of the basin has been modified by the advance of the last continental ice sheets. The line of farthest advance crosses the northwestern part of the region running from just west of Franklin, Pennsylvania, to just east of Jamestown, New York. The topography of the glaciated area is generally that of rolling plains with gentle slopes. Many lakes and swamps have been formed on the glacial deposits because the post-glacial drainage has not had time to develop a significant degree of integration. South and east of the glacial advance, the topography displays moderate to strong relief. In the mountain upland and high plateau areas of the basin, the land is highly dissected by its drainage. For example, the Conemaugh River and Loyalhanna Creek gorges are over 1,000 feet deep. The highest points in the upland areas are above 2,500 feet in elevation.

Bituminous coal reserves are present in 14 of the 19 Pennsylvania counties that are wholly or partly in the basin, amounting to some 57 percent of the total basin land area (Figure 37). Coal has been mined in all but one of these 14 counties, with Armstrong, Clarion, and Indiana having been the principal producing counties. The recoverable

coal reserve in the Allegheny River basin portion of these counties is estimated to be nearly 11 billion tons. There are no coal deposits in the New York portion of the basin.

By 1877, bituminous coal mining in western Pennsylvania had evolved into a significant industry, producing 1.3 million tons in that year. From this early beginning, production of coal in western Pennsylvania has not fallen under 50 million per year since 1894. A peak annual production of 177 million tons was reached in 1918. Production in the Allegheny River basin in 1965 was 30 million tons.

Mine Drainage Sources and Their Effect on Stream Quality

Significant mine drainage stream pollution exists in 14 Pennsylvania counties of the basin. Nearly all of the 979 miles of continuously affected and 87 miles of intermittently affected streams are found in that portion of the watershed south of a general east-west line between Franklin, Pennsylvania, Venango County and St. Marys, Pennsylvania in Elk County. Stream pollution from mine drainage is particularly acute in terms of numbers of streams and total length of streams affected in Armstrong, Cambria, Clarion, Indiana, Somerset, and Westmoreland Counties. Table 5 gives the miles of polluted streams by watershed.

Table 5 - Lengths of Streams Significantly Affected by
Mine Drainage, Allegheny River Basin

	Drainage Area (square miles)	Continuously Polluted (miles)	Intermit- tently Polluted (miles)	Total
Allegheny River	11,733	30		30
Minor Tributaries		281	58	339
Kiskiminetas River	1,892	24		24
Tributaries		40	5	45
Conemaugh River	1,376	48		48
Tributaries		310	6	316
Loyalhanna Creek	300	21		21
Tributaries		31		31
Clarion River	1,232	21		21
Tributaries		173	18	191
		979	+ 87 =	1,671

Field studies have been made jointly by the Pennsylvania Department of Health and FWPCA to locate and characterize individual sources of mine drainage pollution in the Clarion and Kiskiminetas River watersheds. The results of these studies are summarized in the table on the following page.

Since 85 percent of the acidity ~~formed~~ in the basin originates in the Clarion and Kiskiminetas River watersheds. These watersheds contain most of the mine drainage sources in the Allegheny basin. It is clear that abandoned underground mines and reclaimed surface-mined lands are the major sources of pollution. Active underground mines are significant in particular in the Blacklick Creek watershed.

A significant fact that is true in nearly all cases in the inventories that have been carried out is exemplified by the survey results in the Clarion River basin. In this area, 10 percent of the sources of acid discharge were found to contribute 70 percent of the acid drainage. In this and many other cases, control over a relatively small percentage of major sources will return the streams involved to a satisfactory condition.

It is estimated that an average of 2,400 tons/day of acidity are formed in the Allegheny basin and that 1,600 tons/day of net acidity enters streams in the basin. The estimate of total acidity formed is based on average sulfate loadings in the Allegheny River at Kittanning and in the Kiskiminetas River at Leechburg (Figures 38 and 39). Table 6 lists the streams in the Allegheny basin that carried more than 5 tons/day of net acidity during the sampling period in 1966.

Much of the acidity discharged to streams in the Allegheny basin is neutralized before it reaches the lower Allegheny. An average of only 150 tons/day of unneutralized acidity reached Pittsburgh during a 1965-1966 study (Shapiro and others, 1966). Water quality records show that acid conditions in the lower Allegheny River are particularly acute during periods of low flow when the percentage contribution of flow to the main stem by the Kiskiminetas is greater than normal. When roughly 30 percent of the flow in the Allegheny is from the Kiskiminetas River, fish kills are expected. One million fish were killed in the Allegheny River below the Kiskiminetas due to acid conditions during the period August 19-23, 1966.

A detailed discussion of the mine drainage sources in the Allegheny basin, and their effect on stream quality follows.

Inactive Operations

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Table 6 - Net Acidity Loads, Allegheny River Basin

Sampling Station Number	Stream	Net Acidity Load (tons/day)
519	Little Toby Creek (tributary to Toby Creek, Elk County)	8.4
518	Toby Creek at the Clarion River (Elk County)	7.5
517	Mill Creek at the Clarion River	8.5
516	Toby Creek at the Clarion River (Clarion County)	24
515	Piney Creek at the Clarion River	9.6
514	Deer Creek at the Clarion River	6.9
513	Licking Creek at the Clarion River	8.4
524	Clarion River at Mouth	63
558	Pine Run at Mahoning Creek	6.1
560	Crooked Creek at Mouth	17
493	Dark Shade Creek	12
574	Two Lick Creek	38
577	North Branch Blacklick Creek	88
573	Blacklick Creek at the Kiskiminetas R.	213
494	Shade Creek	13
570	Loyalhanna Creek at the Kiskiminetas River	57
569	Blacklegs Creek at Mouth	5
579	Conemaugh River at USGS Gage at Seward	86
567	Kiskiminetas River at Vandergrift, Pennsylvania	494
566	Allegheny River at Natrona, Penn- sylvania	245

Although the Allegheny River receives small amounts of mine drainage from minor tributaries in Venango County, the first mine drainage of any dimension is received from the Clarion River in western Clarion County. The Clarion River discharged an average of 63 tons/day net acidity to the Allegheny River during the 1966 survey.

In the moderately polluted upper Clarion River basin, mine drainage enters the headwaters of East Branch Clarion River. At sampling station 522 below the East Branch Reservoir (Fig. 37, Table 7) the pH during the sampling period ranged from 5.5 to 6.6 and the net acidity load was 4 tons/day. The main stem Clarion receives only minor drainage increments below the East Branch Reservoir until the entry of Toby Creek in southern Elk County. During the sampling period, Toby Creek added an acidity load of 7.5 tons/day to the Clarion and had a pH range of 3.6 to 4.1 (sta. 518).

Very little mine drainage enters the Clarion River between Toby Creek and station 523 on the river below Cooksburg, Pennsylvania. At station 523, the pH ranged from 5.7 to 6.7 and the average alkalinity slightly exceeded the average acidity. Total mineralization of the water was relatively low.

The Clarion River is grossly polluted by mine drainage in its lower section. At the Cooksburg station (Sta. 523), the Clarion was found to have a pH range of 5.7 to 6.7. At its mouth, the Clarion carried an acid load of 63 tons/day and exhibited a pH range of 4.1 to 5.3, during the survey. Between Cooksburg and the mouth, the Clarion River receives mine drainage from a number of very poor quality tributaries. The principal contributing tributaries in this reach and their acid loads are presented in the following table.

Station Number:	Stream:	Location:	pH Range	Average Net Acidity Load (tons/day)
517	Mill Creek	Mouth	2.9-3.2	8.5
518	Toby Creek	Mouth	2.8-3.1	24
515	Piney Creek	Mouth	3.4-4.0	9.6
514	Deer Creek	Mouth	3.2-3.4	6.9
513	Licking Creek	Mouth	2.6-3.1	8.4

The Clarion River watershed contains over 200 miles of mine drainage polluted streams. The principal problem areas are acid tributary watersheds in the lower basin in Clarion County. The acidity load received by the Clarion River in this reach is about 57 tons/day.

At Parker Bridge, about two and one-half miles below the mouth of the Clarion River (Sta. 565), the Allegheny had assimilated the large acidity load from the Clarion. The minimum pH at this location was 6.4, and the alkalinity was consistently greater than the acidity. Between the Clarion and Kiskiminetas Rivers, the Allegheny River receives significant loads of mine drainage indicators such as sulfate and hardness from Redbank, Mahoning, and Crooked Creeks. An acidity load of 17 tons/day is discharged by Crooked Creek (Sta. 560) Redbank and Mahoning Creeks are essentially neutral at their mouths (Stas. 525 & 557).

Thirty miles above Pittsburgh, the Kiskiminetas River enters the Allegheny. During the 1966 survey it discharged a massive load of 494 tons/day of acidity, as measured at Vandergrift, Pennsylvania. The pH of the stream ranged from 3.0 to 3.6 and the alkalinity was depleted throughout the survey. Long term water quality records (Fig. 39) show that an average of about 1,700 tons/day of acidity are formed in the Kiskiminetas River basin 900 tons/day of which are discharged to the Allegheny River as acidity.

Within the Kiskiminetas watershed there are about 485 miles of streams polluted by mine drainage. A large number of streams are acid even in the upper headwater areas of Somerset and Cambria Counties. The Conemaugh River above Johnstown carried an acidity load of 25 tons/day originating from the watersheds of both the North and South Branches (Sta. 581).

Stony Creek, which enters the Conemaugh River at Johnstown, drains 466 square miles of the southern portion of the headwaters area and contains over 100 miles of acid streams. The principal tributaries of Stony Creek are polluted by mine drainage. Shade Creek carried an acidity load of 13 tons/day (Sta. 494). Additional acidity entering the Conemaugh between Johnstown and station 579 raised the net acidity load in the river to 80 tons/day.

Blacklick Creek and many of its tributaries are acid over their entire length. The Blacklick Creek watershed contains over 100 miles of drainage polluted streams. The pH at the mouth of Blacklick Creek ranged from 2.5 to 2.9 and the total acidity concentration from 452 to 897 mg/l (Sta. 573). The acidity load of 213 tons/day discharged from Blacklick Creek was 43 percent of the acid load discharged by the Kiskiminetas River.

An acidity load of 88 tons/day was measured on the North Branch Blacklick Creek at Ripton in Cambria County (Sta. 577). Although the watershed above this point represents only 14 percent of the Blacklick Creek watershed, 42 percent of the total acidity load of Blacklick Creek was measured here. The load at this station is about 20 percent of that measured in the Kiskiminetas at Vandergrift. Two Lick Creek discharged an acidity load of 38 tons/day to Blacklick Creek (Sta. 574).

The Conemaugh River below Blairsville (Sta. 575) carried an acidity load of 400 tons/day, contained no alkalinity, and exhibited a pH range of 2.9 to 3.3. Continuing downstream, the Kiskiminetas River is formed where the Conemaugh River and Loyalhanna Creek converge just above the Armstrong-Indiana County line. Loyalhanna Creek is an acid stream over much of its length and contributed a net acidity load of 57 tons/day. The pH ranged from 3.3 to 4.7 and the alkalinity was completely depleted (Sta. 570).

From the origin of the Kiskiminetas River to its mouth there are a number of small acid contributing tributaries. The largest of these is Blacklege Creek which contained a net acidity load at its mouth of 5 tons/day (Sta. 569).

During the 1966 water quality survey, the Kiskiminetas River at Vandergrift contained an average manganese concentration of 23.2 mg/l. High manganese concentrations (9-23.2 mg/l) were found at all stations in the Conemaugh and Kiskiminetas Rivers below Johnstown. Manganese concentrations in tributaries to the Conemaugh-Kiskiminetas main stem averaged about one-tenth of the main stem concentrations. The higher

manganese levels in the main stem below Johnstown are probably due to discharges from the steel industry in the Johnstown area.

The Conemaugh-Kiskiminetas River is an acid stream over its entire length and the river system is grossly polluted by coal mine drainage. Acid-sterile streams in this watershed are the rule and not the exception.

Although the Allegheny River possessed adequate dilution and neutralizing capability to assimilate mine drainage waters received above the mouth of the Kiskiminetas River, the water quality is significantly degraded below this point. The Allegheny River at Natrona, Pennsylvania (Sta. 566) carried an average net acidity load of 245 tons/day and had a pH range of 4.0 to 6.8. The total acidity concentration exceeded the alkalinity concentration during two thirds of the survey period. However, the acidity concentration was generally below 30 mg/l.

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Table 7 - Water quality data, Allegheny River basin

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Total Manganese (mg/l)	Total Aluminum (mg/l)	Flow (cfs)
490	7	6.5 7.1 Avg.	0.0 12.0 6.7	13.0 32.0 19.6	76.0 172.0 136.1	34.0 145.0 106.0	0.0 2.0 0.6	0.1 0.7 0.4	0.0 2.5 1.1(6)*	8.4 70.0 19.9
492	7	6.2 7.8 Avg.	3.0 10.0 6.7	5.0 15.0 9.9	7.0 60.0 34.0	4.0 25.0 12.9	0.0 1.0 0.2	0.0 0.2 0.1	0.0 2.1 0.5(6)	1.5 83.0 17.7
493	7	2.8 4.4 Avg.	107.0 445.0 270.3	0.0 0.0 0.0	148.0 363.0 260.3	48.0 825.0 501.4	7.5 73.2 46.7	0.2 8.2 5.1	10.4 30.8 22.3(6)	9.6 50.0 20.5
494	7	2.7 3.8 Avg.	53.0 255.0 148.0	0.0 0.0 0.0	86.0 332.0 184.9	120.0 490.0 310.7	6.7 22.1 12.0	0.1 6.0 3.4	2.5 30.8 15.8(6)	9.0 120.0 49.6
495	7	6.5 7.4 Avg.	0.0 25.0 9.0	13.0 33.0 22.9	94.0 502.0 297.9	71.0 475.0 284.4	0.4 2.2 1.3	0.0 0.4 0.2	0.3 3.6 2.1(6)	5.0 65.0 18.9
499	7	6.3 7.2 Avg.	2.0 12.0 7.1	13.0 43.0 27.3	60.0 285.0 143.0	80.0 135.0 106.8(6)	0.0 1.0 0.3	0.0 0.2 0.1	0.0 2.9 1.2(6)	5.4 116.0 26.2
501	7	3.2 6.0 Avg.	9.0 105.0 36.9	0.0 12.0 3.0	60.0 127.0 85.6	36.0 194.0 108.3	3.1 12.2 6.4	0.0 0.8 0.3	1.1 8.4 3.3(6)	10.5 40.0 22.7
503	6	7.0 7.9 Avg.	0.0 14.0 7.0	39.0 73.0 55.5	68.0 152.0 110.7	15.0 25.0 19.2	0.1 1.0 0.5	0.2 0.3 0.3	0.7 3.9 1.6	170.0 600.0 380.0
504	6	6.7 6.9 Avg.	0.0 19.0 12.5	35.0 62.0 46.7	337.0 838.0 562.7	5.0 30.0 16.5	0.0 4.8 1.5	0.0 0.5 0.2	0.7 30.2 9.7	7.0 23.8 15.2

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Total Manganese (mg/l)	Total Aluminum (mg/l)	Flow (cfs)
506	6	7.1 7.4 Avg.	0.0 18.0 7.5	46.0 81.0 65.2	75.0 135.0 99.5	5.0 30.0 19.0	0.3 1.4 0.8	0.2 0.5 0.3	0.1 6.7 2.4	470.0 1900.0 969.2
508	6	6.8 7.8 Avg.	0.0 13.0 7.0	15.0 40.0 26.8	25.0 59.0 36.7	9.0 35.0 22.3	0.1 0.3 0.2	0.0 0.2 0.1	0.0 2.0 0.8	6.0 38.0 18.4
509	6	7.6 8.7 Avg.	0.0 9.0 4.7	46.0 74.0 60.7	68.0 132.0 90.3	15.0 70.0 33.5	0.4 1.0 0.7	0.0 0.5 0.2	1.0 2.8 1.9	740.0 3280.0 1752.7
510	6	7.1 7.7 Avg.	0.0 12.0 5.5	24.0 52.0 35.3	59.0 84.0 68.7	20.0 55.0 45.3	0.0 0.5 0.3	0.0 0.3 0.1	0.0 2.1 1.1	.8.0 28.0 20.0
511	6	4.8 7.5 Avg.	10.0 49.0 24.8	3.0 16.0 7.3	256.0 290.0 278.0	150.0 260.0 219.2	0.3 4.3 2.0	3.6 5.8 4.7	1.5 10.5 4.4	10.8 16.0 13.6
512	6	4.4 6.4 Avg.	18.0 39.0 25.5	0.0 10.0 3.7	81.0 120.0 100.8	50.0 110.0 90.8	0.5 0.8 0.6	1.9 2.9 2.3	1.4 4.6 2.9	19.6 186.0 53.3
514	6	3.2 3.4 Avg.	101.0 157.0 134.0	0.0 0.0 0.0	134.0 245.0 188.7	140.0 390.0 280.8	1.1 14.8 4.8(5)	7.2 11.4 8.9(5)	4.9 16.7 11.6(5)	14.5 24.0 19.3

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Total Manganese (mg/l)	Total Aluminum (mg/l)	Flow (cfs)
515	6	3.4 4.0 Avg.	72.0 218.0 140.0	0.0 0.0 0.0	268.0 340.0 288.8	105.0 450.0 342.5	0.7 4.8 3.1	11.0 17.8 14.0	2.8 25.5 12.2	1.0 90.0 24.3
516	6	2.8 3.1 Avg.	735.0 1226.0 969.7	0.0 0.0 0.0	276.0 552.0 414.7	350.0 1900.0 964.2	79.2 144.0 110.4(3)	12.0 60.0 38.0	67.2 139.4 108.5(4)	3.0 15.0 10.0
517	6	2.9 3.2 Avg.	187.0 465.0 279.7	0.0 0.0 0.0	69.0 460.0 337.0	165.0 775.0 385.0	1.4 18.0 10.6	20.2 29.3 26.0	4.0 27.4 15.0	5.1 17.5 11.8
518	6	3.6 4.1 Avg.	62.0 236.0 125.7	0.0 0.0 0.0	221.0 313.0 271.8	140.0 440.0 285.8	0.2 1.2 0.8	5.4 13.8 7.8	6.1 12.6 9.8	9.5 54.9 28.8
519	6	3.0 3.4 Avg.	132.0 2840.0 651.8	0.0 0.0 0.0	300.0 4160.0 1032.8	150.0 950.0 431.7	0.4 60.1 13.3	9.6 38.0 15.8	2.0 36.0 18.0	8.2 20.3 14.6
522	6	5.5 6.6 Avg.	10.0 18.0 13.5	2.0 7.0 3.3	20.0 36.0 24.3	23.0 365.0 96.2	0.1 0.2 0.2	0.5 0.9 0.8	0.2 1.5 1.0	121.0 170.0 147.8
523	6	5.7 6.7 Avg.	1.0 22.0 13.3	10.0 18.0 13.5	50.0 98.0 86.0	15.0 75.0 55.8	0.1 2.6 1.1	0.2 0.5 0.3	0.8 6.6 3.7	232.0 335.0 286.3
524	6	4.1 5.3 Avg.	25.0 40.0 32.7	0.0 4.0 2.0	100.0 158.0 113.8	90.0 210.0 117.2	0.2 1.4 0.7	2.3 4.4 3.0	1.9 7.5 4.5	68.0 2000.0 761.3

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Total Manganese (mg/l)	Total Aluminum (mg/l)	Flow (cfs)
525	6	6.4 7.2 Avg.	9.0 19.0 13.0	6.0 17.0 11.8	155.0 240.0 183.8	45.0 215.0 159.2	0.2 1.2 0.5	0.0 1.0 0.5	0.9 5.8 2.2	44.0 128.0 85.3
554	6	6.4 7.4 Avg.	0.0 18.0 6.8	35.0 70.0 51.8	20.0 62.0 35.7	6.0 35.0 17.7	0.5 1.4 0.8	0.0 0.2 0.1	0.4 5.0 1.5	6.5 17.7 11.9
555	6	6.3 7.4 Avg.	0.0 18.0 10.0	8.0 40.0 21.8	90.0 149.0 127.7	110.0 145.0 130.8	0.3 0.4 0.4	0.0 0.3 0.1	1.0 1.9 1.3	12.0 38.0 24.3
557	6	6.6 7.0 Avg.	1.0 15.0 9.5	11.0 36.0 21.2	120.0 215.0 158.2	120.0 195.0 157.0(5)	0.0 0.7 0.3	0.1 0.7 0.3	0.2 3.2 1.1	95.0 300.0 193.7
558	6	2.8 3.4 Avg.	97.0 336.0 206.0	0.0 0.0 0.0	207.0 314.0 256.5	340.0 560.0 411.3(4)*13.8(5)	2.6 34.6 6.4(5)	4.1 10.2 6.4(5)	3.2 39.8 16.9(5)	8.0 14.2 11.6
560	6	3.7 4.7 Avg.	33.0 120.0 74.2	0.0 0.0 0.0	111.0 222.0 169.5	190.0 450.0 287.0(5)	0.0 0.6 0.4	1.0 4.8 2.8	1.6 12.3 5.8	50.0 104.0 76.2
561	6	6.9 7.1 Avg.	0.0 90.0 21.3	31.0 280.0 78.0	147.0 1480.0 411.7	112.0 1100.0 329.4(5)	0.0 1.3 0.6	0.0 0.3 0.2	0.0 3.8 1.4	8.8 14.0 11.6
562	6	6.4 7.0 Avg.	0.0 20.0 10.2	13.0 30.0 20.2	147.0 345.0 206.3	160.0 400.0 233.8(4)	0.0 1.6 1.0	0.7 1.1 0.9	0.0 2.2 1.0	12.8 32.0 23.5

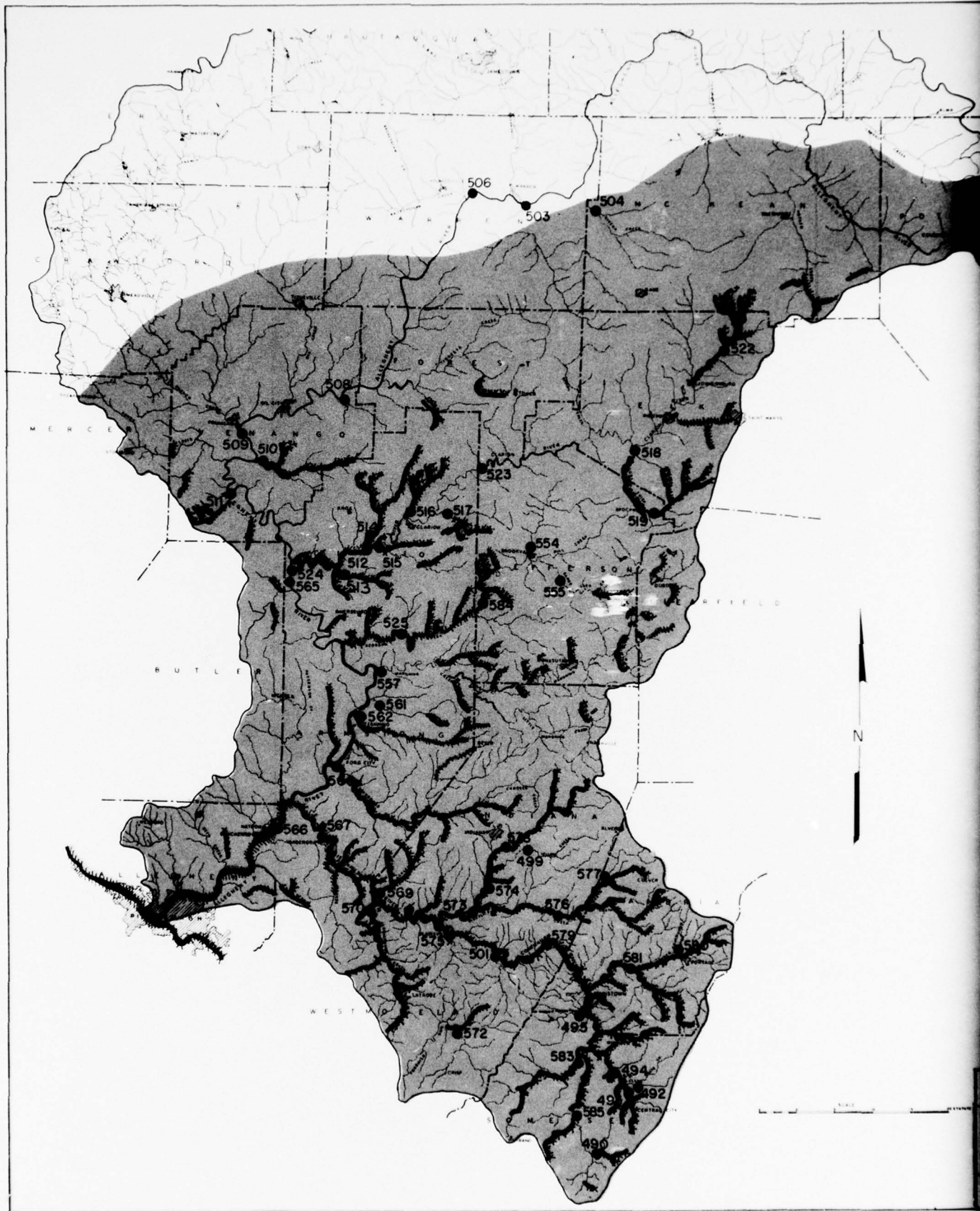
Map Station No.	No. of Samples	pH		Acidity (mg/l)		Alkalinity (mg/l)		Hardness (mg/l)		Sulfate (mg/l)		Iron (mg/l)		Total Manganese (mg/l)		Total Aluminum (mg/l)		Flow (cfs)	
		Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
565	6	6.4	7.7	7.7	0.0	13.0	7.7	36.0	74.0	28.0	175.0	0.3	0.7	0.2	0.7	0.7	3.1	1392.0	4876.0
566	6	4.0	6.8	6.8	2.0	158.0	37.3	0.0	115.0	95.0	270.0	0.2	1.1	1.6	5.2	0.5	5.1	1866.0	12840.0
567	6	3.0	3.6	3.6	159.0	259.0	221.7	0.0	264.0	425.0	700.0	5.5	32.6	9.0	76.9	12.2	39.8	421.0	1136.0
569	6	3.1	5.0	5.0	60.0	171.0	112.8	0.0	80.0	340.0	600.0	3.4	21.6	1.9	2.6	5.6	31.9	5.0	29.0
570	6	3.3	4.7	4.7	104.0	193.0	141.8	0.0	382.0	120.0	680.0	2.4	18.5	4.1	8.2	0.0	17.9	60.0	296.0
572	6	6.7	10.1	10.1	5.0	11.0	8.7	12.0	348.2	435.0(5)	11.4	0.0	0.3	5.8	6.2	0.0	4.4	136.3	25.2
573	6	2.5	2.9	2.9	452.0	897.0	601.5	0.0	21.0	0.0	15.0	0.0	1.6	0.0	0.2	0.0	1.7	16.5	37.9
574	6	3.0	4.3	4.3	189.0	467.0	308.7	0.0	35.2(5)	130.0	920.0	48.0	158.4	3.2	5.5	22.2	168.0	53.0	330.0
									248.8	522.5(4)	93.8			4.0	82.8			125.2	
									222.0	130.0	27.8			1.2	10.8			21.0	
									381.0	750.0	40.8			5.7	84.0			86.0	
									284.0	528.0(5)	34.7			3.8	44.5			50.3	

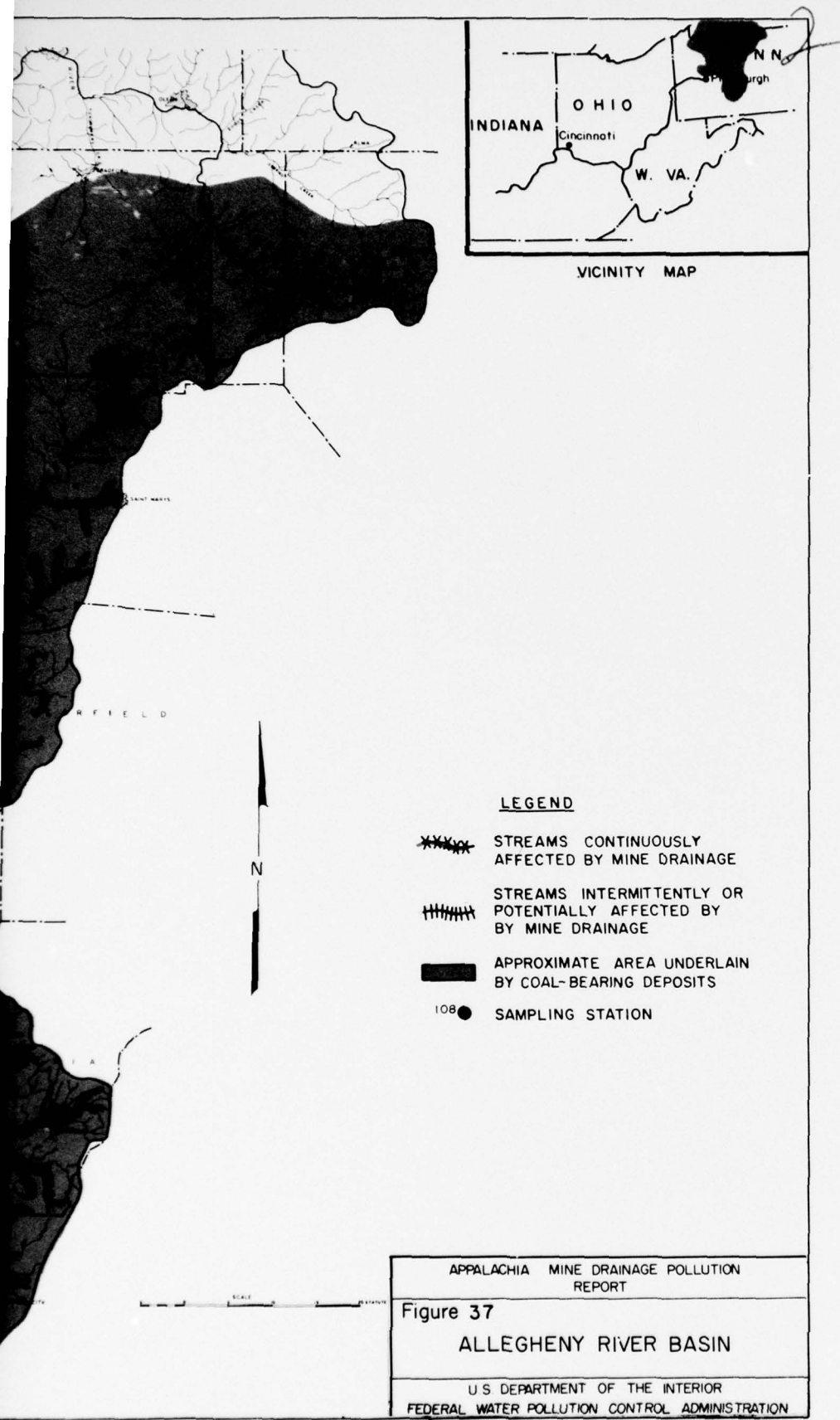
Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity		Hardness (mg/l)	Sulfate (mg/l)	Iron (mg/l)	Total		Flow (cfs)
				(mg/l)	(mg/l)				Manganese (mg/l)	Aluminum (mg/l)	
575	Min.	2.9	167.0	0.0	234.0	440.0	4.3	8.8	6.4	160.0	
	Max.	3.3	274.0	0.0	320.0	475.0	12.5	22.8	26.3	901.0	
	Avg.		207.3	0.0	274.5	456.3(4)*	7.8	15.1	13.9	724.8	
576	Min.	2.7	614.0	0.0	247.0	1450.0	91.0	3.5	70.0	56.0	
	Max.	2.8	1592.0	0.0	410.0	2500.0	312.0	6.5	176.4	105.0	
	Avg.		999.8	0.0	311.2	1845.8	215.2	4.6	124.8(5)	73.8	
577	Min.	2.7	711.0	0.0	110.0	1150.0	163.2	2.9	14.0	21.0	
	Max.	2.9	1572.0	0.0	342.0	2500.0	374.4	7.0	179.2	47.5	
	Avg.		1010.5	0.0	272.0(5)	1720.0(5)	257.1	5.2	96.8	35.4	
578	Min.	3.0	95.0	0.0	202.0	50.0	1.4	2.6	7.8	8.0	
	Max.	5.2	261.0	2.0	414.0	450.0	11.0	5.9	35.3	42.0	
	Avg.		169.5	0.7	283.0	315.0(5)	5.5(5)	4.0	19.1(5)	28.1	
579	Min.	5.4	79.0	3.0	140.0	400.0	7.7	22.0	0.1	229.0	
	Max.	6.8	160.0	76.0	370.0	840.0	67.2	41.7	47.6	512.0	
	Avg.		106.5	19.3	257.8	580.0(5)	22.0	29.8(5)	12.9	373.3	
580	Min.	6.7	0.0	20.0	80.0	20.0	0.0	0.2	0.0	0.5	
	Max.	8.3	15.0	102.0	130.0	88.0	1.5	0.6	2.5	3.8	
	Avg.		4.0	71.5	95.2	49.6(5)	0.5	0.3	0.6	2.4	
581	Min.	3.0	184.0	0.0	212.0	475.0	10.6	3.7	0.0	0.0	
	Max.	4.2	330.0	0.0	452.0	805.0	26.4	5.7	41.4	80.0	
	Avg.		244.2	0.0	336.3	598.0(5)	17.8	4.4	17.7	40.9	
583	Min.	5.1	0.0	2.0	95.0	62.0	0.0	0.0	0.2	0.1	
	Max.	6.9	43.0	38.0	200.0	215.0	0.5	2.3	3.6	12.0	
	Avg.		17.0	20.3	145.8	147.4(5)	0.2	1.1	1.5	3.9	
584	Min.	6.0	0.0	10.0	113.0	75.0	0.6	0.5	0.9	28.0	
	Max.	7.2	16.0	35.0	140.0	120.0	3.6	1.4	6.4	82.5	
	Avg.		6.7	26.0	128.7	97.5	1.7	0.9	2.4	59.9	

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Total Manganese (mg/l)	Total Aluminum (mg/l)	Flow (cfs)
585	Min.	6.6	5.0	12.0	187.0	155.0	0.0	0.2	0.0	14.5
	Max.	7.0	16.0	28.0	237.0	235.0	0.5	0.7	1.9	30.0
	Avg.		11.5	19.7	210.0	193.8(5)	0.2	0.5	0.6	23.8

* () Indicates the number of samples used in averages when other than the maximum.

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LEGEND

- XXX STREAMS CONTINUOUSLY
AFFECTED BY MINE DRAINAGE
- ||||| STREAMS INTERMITTENTLY OR
POTENTIALLY AFFECTED BY
BY MINE DRAINAGE
- APPROXIMATE AREA UNDERLAIN
BY COAL-BEARING DEPOSITS
- 108 ● SAMPLING STATION

APPALACHIA MINE DRAINAGE POLLUTION
REPORT

Figure 37

ALLEGHENY RIVER BASIN

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

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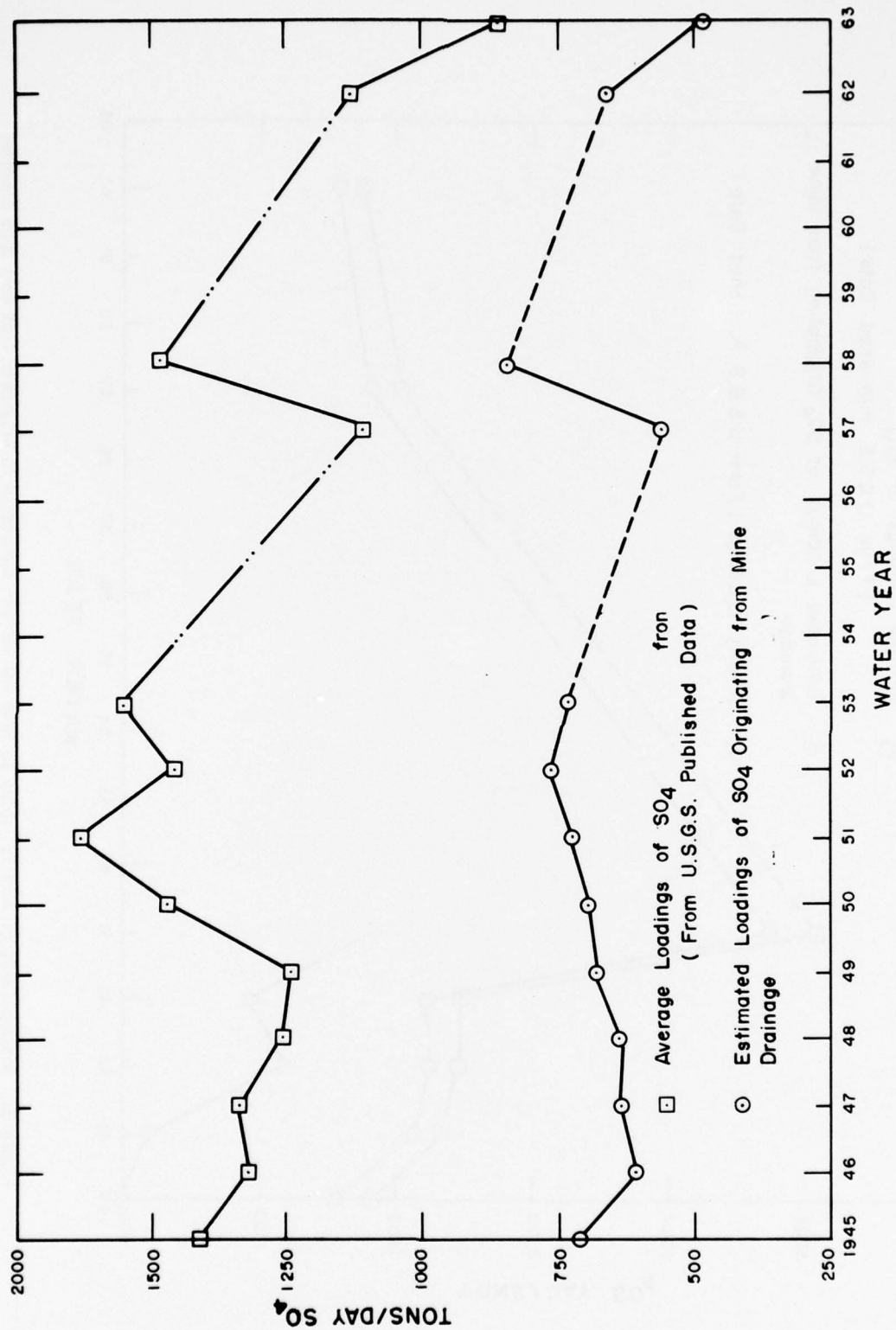


Figure 38. Average loads of total sulfate and sulfate considered to originate from coal mine drainage carried by the Allegheny River at Kittanning, Pennsylvania.

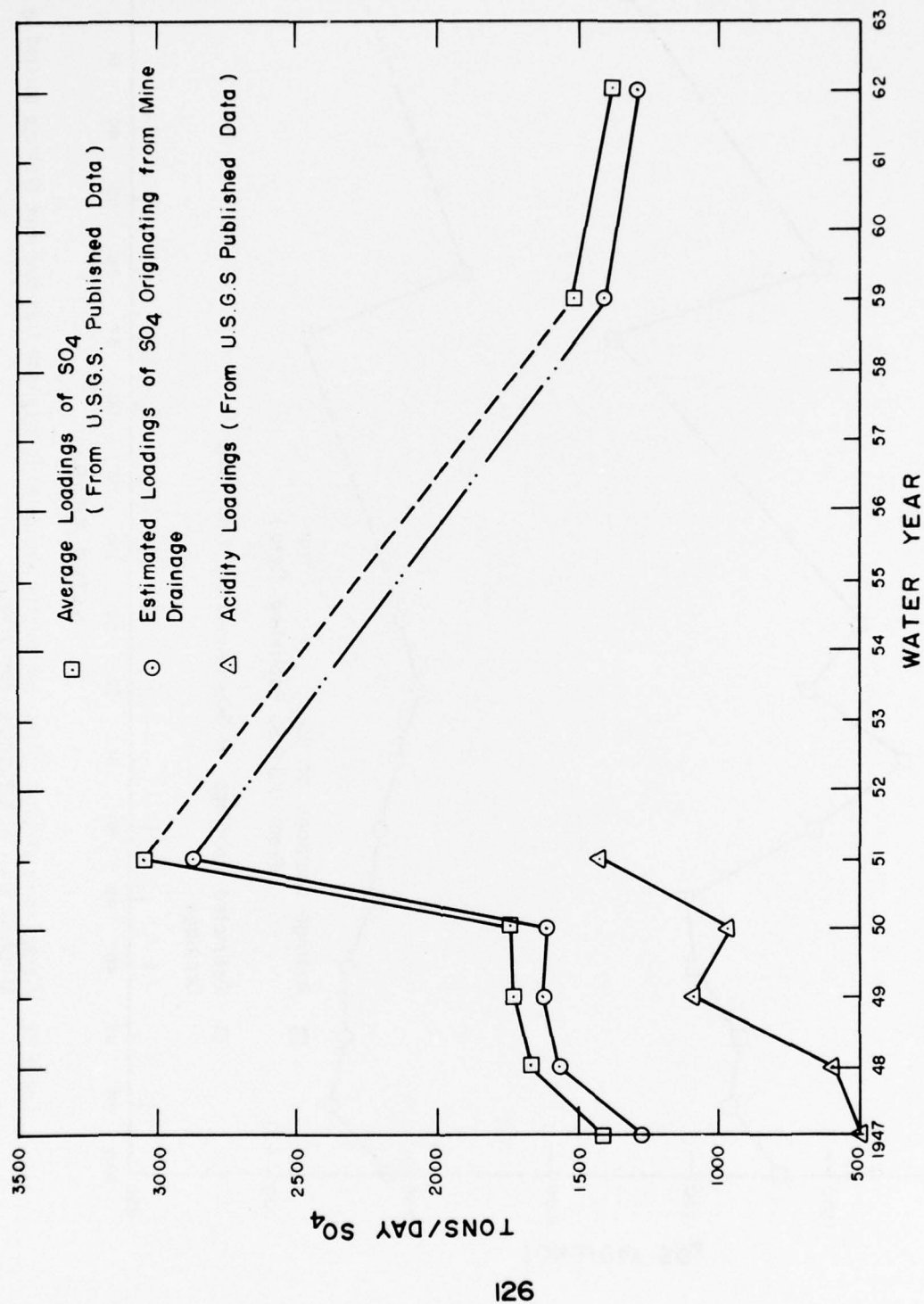


Figure 39. Average loads of acidity, total sulfate and sulfate considered to originate from coal mine drainage carried by the Kiskiminetas River at Vandergrift, Pennsylvania.

Monongahela River Basin

Description

The Monongahela River basin includes about 7,380 square miles in northern West Virginia, southwestern Pennsylvania, and northwestern Maryland all of which is within the Appalachian Region (Fig 40). West Virginia contains the largest share of the basin, 4,150 square miles. Pennsylvania and Maryland contain approximately 2,730 and 500 square miles, respectively. The basin is bounded on the west by main stem Ohio River drainage, on the south by the Little Kanawha and Kanawha River basins, on the east by the Potomac River basin, and on the north by the Allegheny River basin. It includes all or part of 11 counties in West Virginia, six counties in Pennsylvania, and one county in Maryland.

The Monongahela River is formed by the confluence of the West Fork and Tygart Valley Rivers at Fairmont, W. Va. The river flows 129 miles in a northerly direction and joins the Allegheny at Pittsburgh to form the Ohio River. Major tributaries are the Youghiogheny, Cheat, West Fork, and Tygart Valley Rivers. The Monongahela basin is maintained for navigation by lock and dam installations through its entire length.

This area of the Monongahela River basin represents a mature plateau of fine texture with moderate to strong relief. Erosion has reduced almost all the land area to slope, the terrain is rugged, and the valleys are deep and narrow. Flat areas are limited to narrow flood plains and some terraces and flat-topped hills. The elevations of the basin range from a high of about 4,600 feet in the headwaters of the Cheat River to about 700 feet at Pittsburgh, Pennsylvania, giving a maximum relief of nearly 4,000 feet.

Bituminous coal reserves are present in 17 of the 18 counties that are wholly or partly in the basin. These reserves have been estimated to be about 23 billion tons. Coal has been mined in this area for some 200 years. Some mining has been done in all 17 counties, and in 1965 production from approximately 750 mines was about 65 million tons. Marion, Monongalia, Harrison, Preston, and Barbour in West Virginia, and Green, Washington, Westmoreland, Fayette, Somerset, and Allegheny in Pennsylvania were the principal producing counties.

Mine Drainage Sources and Their Effect on Stream Quality

Records of State and Federal agencies indicate that more than 3,000 coal mines have been opened in the Monongahela basin. Each of these mines is a possible source of drainage pollution and many of these mines discharge drainage from a number of points.

Work initiated as a result of the Monongahela River Conference of August 7, 1963, (U.S. Department of Health, Education, and Welfare, 1963) has led to the location and description of over 7,000 underground and surface mines, refuse piles, and coal preparation plants that are present or potential pollution sources. Of these sites that were located and described, about 3,000 were found to be discharging pollutants at the time they were visited. The distribution of pollution sources by type and the relative pollution contributions of the various types are shown in Table 1-A. The table shows that inactive underground mines are the largest single pollution source, contributing about 41 percent of the acidity measured. Active underground mines were contributing about 29 percent of acidity, bringing the total contribution of underground mines to 70 percent. Detailed reports, in which each of the mine drainage sources that were inventoried are listed and pollution abatement measures and costs are discussed, are being prepared for 30 sub-areas of the Monongahela River basin. These reports will be submitted to the Technical Committee of the Monongahela River Enforcement Conference and subsequently to the conferees, which include the States of Maryland, Pennsylvania, and West Virginia, the Ohio River Valley Water Sanitation Commission, and the Federal Government.

Mine drainage pollutants discharged from surface and underground sources cause continuous significant pollution of 1,382 miles of streams and intermittent significant pollution of 289 miles of streams (Table 8).

The significance of these numbers is not obvious in terms of the water uses preempted by this pollution. Further examination shows that, for example, within the Lower West Fork watershed, a highly mined area, 100 percent of the West Fork and 75 percent of the streams directly tributary to the West Fork are severely degraded. The percentage of polluted stream miles as compared to the total stream miles decreases with decreasing tributary size. Only 24 percent of the smallest tributaries are polluted, but these streams are small and remote and do not receive the use accorded the larger streams. Overall, including streams of all sizes, 56 percent of the miles of streams in the West Fork watershed below Clarksburg are severely polluted. In

Table 8 - Lengths of Streams Polluted by Mine
Drainage, Monongahela River Basin

	Drainage Area (square miles)	Continuous (miles)	Intermit- tent(miles)	Total
Monongahela River	8,038	129		129
Minor Tributaries		341	33	374
Youghiogheny River	1,768		105	105
Tributaries		129	27	156
Cheat River	1,424	19	17	36
Tributaries		134	9	143
West Fork River	882	30	18	48
Tributaries		371	20	391
Tygart Valley River	1,369	48		48
Tributaries		181	60	241
		<u>1,382</u>	<u>+</u> 289	<u>= 1,671</u>

contrast, 43 percent of the Buckhannon River is degraded below desirable quality and only 14 percent of the stream miles in this watershed are degraded to this level. The conclusion can easily be reached from glancing at Figure 40 or from statistical exercises such as given above that relatively large amounts of the available miles of the larger more usable streams are badly degraded and that the largest percentage of unaffected or slightly affected stream miles are comprised by the smaller tributaries.

Based on sulfate loadings in the Monongahela River at Charleroi (Figure 41) and in the Youghiogheny River at Sutersville (Figure 42), it is estimated that about 3,000 tons/day of acidity were formed in the Monongahela basin during the period 1945-1958. About 2,500 tons/day were formed in the Monongahela basin above Charlerio and 500 tons/day were formed in the Youghiogheny basin. It is estimated that 1,200 tons/day of unneutralized acidity enters streams in the basin at the present time. Figure 41 shows that the Monongahela River carried an average of 600 tons/day of acidity at Charlerio during 1945-1953.

A comprehensive water quality survey of the streams in the Monongahela River basin was conducted during 1965-1966. Those streams that have been found to carry more than 5 tons/day net acidity are shown in Table 9.

Although the West Fork River receives small amounts of mine drainage from minor headwater tributaries in Lewis County, West Virginia, the first mine drainage of serious proportions is received in Harrison County where virtually every tributary is polluted. Elk Creek alone discharges an average of 6 tons/day net acidity (Sta. 132). Just below Clarksburg, West Virginia, the West Fort River (Sta. 122) discharged

Table 9 - Acidity Loads in Monongahela Basin Streams
Carrying More Than 5 tons/day Net Acidity

Sampling Station Number	Stream	Location	Average Net Acidity Load - tons/day
117	West Fork River	Above Fairmont, W.Va.	156
120	Simpson Creek	Below Bridgeport, W.Va.	29
122	West Fork River	Below Clarksburg, W.Va.	6.5
132	Elk Creek	Near Clarksburg, W. Va.	6
104	Tygart Valley River	Colfax, W. Va.	38
106	Tygart Valley River	Below Tygart Reservoir	14
105	Tygart Valley River	Below Grafton, W.Va.	20
90	Big Sandy Creek	Rockville, W. Va.	5
94	Cheat River	Albright, W. Va.	25
401	Cheat River	Point Marion, Pa.	204
432	Redstone Creek	Below Uniontown, Pa.	5.7
433	Monongahela River	Brownsville, Pa.	470
434	Monongahela River	Millsboro, Pa.	448
425	Monongahela River	Pittsburgh, Pa.	462
429	Monongahela River	Wilson, Pa.	495
441	Monongahela River	Masontown, Pa.	360
127	Monongahela River	Star City, W. Va.	235
128	Deckers Creek	Morgantown, W. Va.	5.3
129	Monongahela River	Hildebrand Lock and Dam	183
130	Monongahela River	Lock 15, Fairmont, W.Va.	118
402	Monongahela River	Point Marion, Pa.	220
403	Youghiogheny River	Above Mckeesport, Allegheny County, Pa.	144
405	Sewickley Creek	Near Mouth, Westmoreland County, Pa.	20
410	Youghiogheny River	Below Connellsville, Pa.	28
415	Youghiogheny River	At Chiopyle, Pa.	35
417	Casselman River	Below confluence of Whites Creek	30
419	Casselman River	At Markleton, Pa.	25
421	Casselman River	Below Piney Creek	5
424	Youghiogheny River	Below Youghiogheny Reservoir	7
447	Youghiogheny River	Above Jacobs, Pa.	26
3	Youghiogheny River	Below Little Youghio- gheny River, Garrett County, Maryland	10
95	Cheat River	Rowlesburg, W.Va.	15

an average of 6.5 tons/day of acidity and had minimum pH of 4.3. The West Fork becomes grossly polluted by mine drainage in its lower section between Clarksburg and Fairmont, W. Va. Many poor quality tributaries enter the stream in this reach. Simpson Creek (Sta. 120) contributed an average net acidity load of 29 tons/day. Other tributaries with significant acidity loads are Ten Mile Creek and Little Ten Mile Creek. At its mouth (Sta. 117) the West Fork River carried an average acidity load of 156 tons/day, had a minimum pH of 3.0 and an average sulfate concentration of over 1000 mg/l.

The Tygart Valley River basin has much less coal mining and fewer mine drainage pollution sources than the West Fork River basin and therefore, contributes less acid to the Monongahela River. The Tygart Valley River is of good quality until it receives mine drainage from Roaring Creek in Randolph County. Further downstream in Barbour County, the Middle Fork River and Buckhannon River contribute acidity. Several small tributaries to the Buckhannon River in Barbour County carry relatively large amounts of acidity. During the survey, the Tygart Valley River just below Philippi (Sta. 108) had a minimum pH of 4.8. At a sampling station just below the Tygart Reservoir in Taylor County (Sta. 106) the average net acidity discharge was 14 tons/day, and the alkalinity was below desirable levels at all times. Further downstream, Threefork Creek contributed more acid, and the Tygart just below Grafton (Sta. 105) carried 30 tons/day of net acidity. At Colfax, near the mouth of the Tygart (Sta. 104), the average net acidity load was 36 tons/day and the minimum pH was 4.7.

The Cheat River receives its first mine drainage pollution from the Blackwater River and its headwater tributaries in Tucker County, West Va. Just below Parsons (Sta. 96) the Cheat River had a minimum pH of 6.7. At Rowlesburg (Sta. 95) the Cheat had a minimum pH of 6.8. At Albright (Sta. 94) the average net acidity load was 25 tons/day and the minimum pH was 4.8. This decrease in quality is attributed to many small acid tributaries in central Randolph County. Minor acid streams such as Big Sandy Creek and Bull Run in the northern part of the County contribute additional acid to Cheat River. Big Sandy Creek at Rockville, W. Va., (Sta. 90) discharged 5 tons/day net acidity. The Cheat River at Point Marion, Pa., below Lake Lynn Reservoir (Sta. 401) discharged an average acid load of 204 tons/day. The pH ranged from 2.9 to 4.2, and sulfate concentrations were as high as 2500 mg/l. Much additional acid is received by the Cheat from mine discharges in Fayette County, Pennsylvania.

The main stem Monongahela River at Fairmont (Sta. 130) discharged 118 tons/day net acidity, and the pH was from 3.9 to 6.2. Many minor tributaries such as Buffalo Creek, Paw Paw Creek, Scotts Run, and Beckers Creek contribute acidity to the Monongahela between Fairmont and Morgantown. The Monongahela at Star City (Sta. 127) discharged 235 tons/day acidity and had a minimum pH of 3.4.

Below the mouth of the Cheat River, many tributaries, including Dunkard Creek, Ten Mile Creek, and Redstone Creek discharge acidity to the Monongahela. At Wilson, Pennsylvania (Sta. 429), the Monongahela River carried an average load of 495 tons/day net acidity and had high concentrations of sulfate, iron, manganese, and hardness. The pH ranged between 5.2 and 6.1.

The Youghiogheny River, the largest tributary to the Monongahela in Pennsylvania, first receives some mine drainage pollution from a few small headwaters tributaries such as Snowy Creek in Garrett County, Maryland. The Youghiogheny River just below the Little Youghiogheny River discharged 10 tons/day of acidity. Neutralization of some of the acidity in the Youghiogheny River decreased the load downstream, and near Friendsville, Maryland, the Youghiogheny carried only 3 tons/day acidity (Sta. 002). Just below the Youghiogheny Reservoir (Sta. 424) the acidity load had slightly increased to an average of 7 tons/day.

The Casselman River, tributary to the Youghiogheny River, is intermittently polluted by mine drainage in its headwaters in Garrett County, Maryland. Several small tributaries downstream from Salisbury, Pennsylvania, discharge acidity to the River, and above Meyersdale, Pennsylvania (Sta. 421), the acid load carried was 5 tons/day. Between Meyersdale, Pennsylvania and Markleton, Pennsylvania (Sta. 419), other minor acid streams increased the net acidity load to 25 tons/day. The Casselman River near its mouth (Sta. 417) had a total average net acidity load of 30 tons/day. The minimum pH at this point was 4.5. At Chiopyle, Somerset County (Sta. 415) the Youghiogheny River carried an average net acidity load of 35 tons/day. This increase in acid load over that measured at the Youghiogheny Reservoir was received primarily from the Casselman River.

Minor tributaries to the Youghiogheny in Fayette, Westmoreland, and Allegheny Counties contributed some acid and produced intermittent stream pollution. Sewickley Creek near its mouth in Westmoreland County (Sta. 405) discharged an average of 20 tons/day net acidity, and had a minimum pH of 4.9. The Youghiogheny at its mouth at McKeesport, Pennsylvania (Sta. 403) carried an average net acidity load of 90 tons/day. The minimum pH was 4.8. At Pittsburgh, Pennsylvania (Sta. 425), the Monongahela River discharged an average net acidity load of 462 tons/day to the Ohio River and had a minimum pH of 5.0. This analysis is based on 9 samples taken during 1966.

Table 10- Water quality data, Monongahela River basin

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Total Manganese (mg/l)	Total Aluminum (mg/l)	Flow (cfs)
90	Min.	6.3(9)	1.0	0.0	28.0	19.0	0.1	0.2		4.2
	Max.	8.2	32.0	18.0	80.0	34.0	0.5	0.5		992.0
	Avg.		16.3	8.8	57.9	26.6	0.2	0.3(5)*	0.3(1)	196.6
94	Min.	3.4	15.0	0.0	32.0	22.0	0.3	0.0		26.0
	Max.	6.5	86.0	3.0	96.0	85.0	2.8	0.3		1600.0
	Avg.		34.3	0.9	71.8	53.8	1.1	0.1(9)		438.2
95	Min.	6.8	5.0	5.0	26.0	7.0	0.1	0.0		146.0
	Max.	7.6	30.0	11.0	69.0	16.0	0.6	0.3		1762.0
	Avg.		16.7	7.3	45.7	10.3(3)	0.2	0.1(4)		870.7
96	Min.	6.7	0.0	4.0	26.0	3.0	0.0	0.0		48.0
	Max.	9.0	47.0	26.0	74.0	40.0	1.0	0.3		1031.0
	Avg.		11.9	13.3	55.1	25.0	0.3	0.1(7)	0.4(1)	356.7
104	Min.	4.7	15.0	0.0	34.0	23.0	0.0	0.0		110.0
	Max.	7.5	41.0	8.0	70.0	42.0	1.1	0.6		2640.0
	Avg.		27.5	1.7	54.7	32.7	0.3	0.3(9)		653.7
105	1	7.3	30.0	5.0	52.0	16.0	0.2	0.3		445.0
106	Min.	6.8	27.0	1.0	44.0	16.0	0.2	0.3		120.0
	Max.	7.2	33.0	2.0	60.0	17.0	0.4	0.6		250.0
	Avg.		30.0	1.5	52.0	16.5	0.3	0.5		185.0
108	Min.	4.8	12.0	0.0	42.0	19.0	0.0	0.0		16.7
	Max.	7.4	39.0	45.0	112.0	92.0	1.3	0.8		2056.0
	Avg.		23.1	7.2	76.0	57.0	0.4	0.4(9)		450.2

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Total Manganese (mg/l)	Total Aluminum (mg/l)	Flow (cfs)
117	12	2.9 3.5 Avg.	17.0 362.0 216.6	0.0 0.0 0.0	100.0 1040.0 782.5	160.0 1400.0 1046.9	3.3 18.2 8.5	0.0 7.6 4.4		20.0 2400.0 353.7
120	9	2.8 3.1 Avg.	300.0 418.0 366.7	0.0 0.0 0.0	708.0 1100.0 928.2	750.0 2750.0 1364.4	13.2 41.6 23.5	0.2 8.6 6.5		5.3 92.0 27.6
122	13	4.3 6.3 Avg.	4.0 75.0 38.2	0.0 50.0 12.8	39.0 960.0 630.8	200.0 1300.0 686.2	0.7 7.8 2.8	1.6 5.1 3.0(9)		2.5 273.0 63.5
127	7	3.4 6.7 Avg.	17.0 128.0 70.9	0.0 9.0 1.9	78.0 1104.0 367.4	80.0 900.0 371.3	1.7 10.4 3.3	0.4 2.2 1.4(4)		345.0 27500.0 5250.6
128	9	3.1 6.8 Avg.	9.0 314.0 156.2	0.0 30.0 4.0	130.0 780.0 426.9	90.0 1225.0 534.1	2.8 10.3 6.8	0.6 6.8 2.6(6)	20.3(1)	0.1 348.0 90.3
129	12	3.3 6.7 Avg.	14.0 115.0 74.7	0.0 9.0 0.8	100.0 360.0 230.2	86.0 1000.0 353.0	0.5 3.8 1.5	0.5 2.5 1.5(9)		205.0 26000.0 3068.3
130	12	3.9 6.2 Avg.	12.0 116.0 55.3	0.0 8.0 1.5	112.0 326.0 197.6	60.0 450.0 198.2	0.4 5.0 1.5	0.4 2.4 1.3(9)		204.0 18200.0 2471.4
132	3	3.0 3.2 Avg.	152.0 260.0 201.7	0.0 0.0 0.0	780.0 1120.0 903.3	660.0 1500.0 1011.7	5.0 15.4 9.5	6.1 8.1 6.9		6.5 18.5 11.4

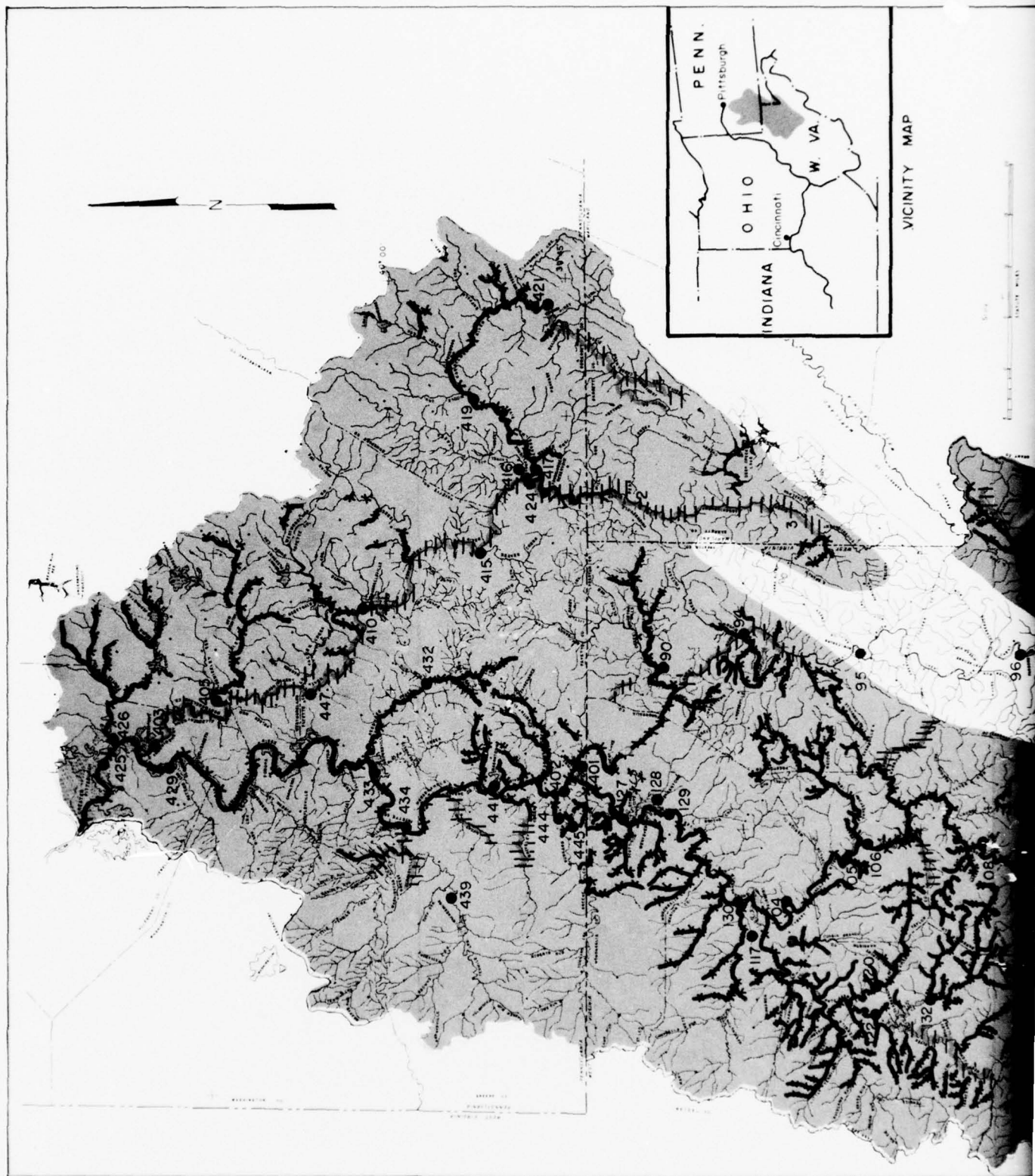
Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Total Manganese (mg/l)	Total Aluminum (mg/l)	Flow (cfs)
401	10	2.2 4.2 Avg.	64.0 281.0 133.7	0.0 0.0 0.0	46.0 371.0 139.0	56.0 2500.0 430.7	1.3 16.4 6.6	0.3 2.3 1.0(6)	4.5 10.3 7.4(2)	53.0 4000.0 920.6
402	13	3.2 4.5 Avg.	13.0 179.0 121.2	0.0 1.0 0.2	84.0 500.0 336.6	100.0 1250.0 505.8	1.0 3.7 2.3	0.4 3.3 1.9(10)		410.0 2800.0 990.0
403	10	4.8 6.3 Avg.	10.0 52.0 34.2	0.0 8.0 4.3	100.0 130.0 143.6(8)	72.0 190.0 143.4(9)	1.4 6.0 3.1(9)	0.3 1.0 0.5(6)		720.0 4644.0 1850.7
405	2	4.9 5.0 Avg.	166.0 245.0 205.5	3.0 9.0 6.0	630.0 770.0 700.0	795.0 1275.0 1035.0	42.1 49.4 45.8	3.4 4.0 3.7		35.4 42.1 38.8
410	10	5.5 6.8 Avg.	7.0 36.0 22.9	6.0 11.0 8.6	62.0 83.0 75.9(9)	20.0 74.0 43.7	0.6 3.9 1.4	0.0 1.4 0.5		375.0 6200.0 1718.0
415	13	4.7 7.8 Avg.	5.0 37.0 23.1	1.0 15.0 7.5	44.0 80.0 59.6	15.0 50.0 28.7	0.0 1.7 0.4	0.0 0.5 0.3		560.0 2420.0 968.5
416	6	6.4 7.3 Avg.	5.0 26.0 14.0	3.0 21.0 13.5	32.0 56.0 45.0	4.0 9.0 6.7	0.0 1.0 0.4	0.0 0.3 0.1		14.5 460.0 199.0
417	10	4.5 6.0 Avg.	12.0 97.0 46.0	0.0 35.0 5.3	64.0 264.0 162.3	61.0 210.0 131.0	0.1 3.8 0.9	0.3 2.7 1.2		36.5 1560.0 420.7

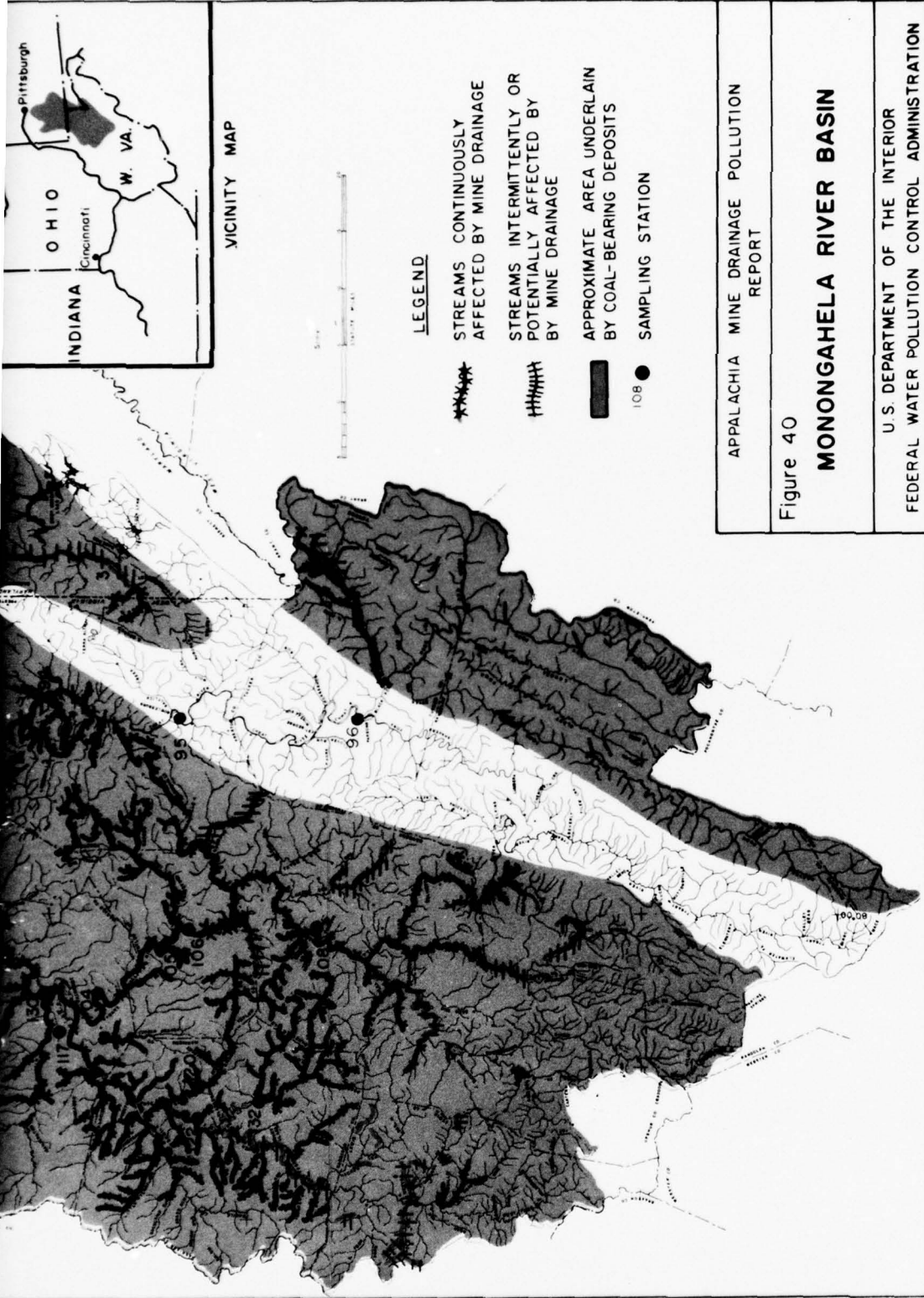
Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Total Manganese (mg/l)	Total Aluminum (mg/l)	Flow (cfs)
419	9	3.6 6.2 Avg.	10.0 120.0 70.9	0.0 4.0 0.6	76.0 318.0 197.1	51.0 470.0 210.1	0.0 2.2 0.8	0.0 2.5 1.5		37.8 1245.0 350.3
421	10	4.1 6.4 Avg.	10.0 181.0 51.0	0.0 15.0 5.3	62.0 284.0 131.7(9)	39.0 310.0 91.8(9)	0.8 6.5 2.6(9)	0.0 3.3 0.8		4.8 405.0 122.4
424	10	5.8 7.2 Avg.	4.0 35.0 18.2	6.0 18.0 11.0	24.0 46.0 37.9	8.0 20.0 11.7	0.2 0.8 0.5	0.0 0.7 0.2		92.5 1200.0 501.8
425	9	5.0 6.9 Avg.	7.0 64.0 37.8(8)	0.0 9.0 6.0(8)	148.0 336.0 277.7(6)	66.0 470.0 281.4	0.8 15.8 3.1	0.4 1.9 1.3		1775.0 29050.0 8953.9
426	1	7.0	45.0	59.0	292.0	195.0	7.0	0.8		50.0
429	6	5.2 6.1 Avg.	5.0 68.0 37.3	0.0 7.0 4.0	118.0 400.0 311.5(4)	80.0 550.0 296.2	0.8 8.5 2.6	0.4 2.9 1.3		842.0 31000.0 11303.7
432	9	6.1 6.6 Avg.	11.0 500.0 247.3	15.0 67.0 41.3	210.0 1670.0 1175.8(8)*	210.0 2900.0 1548.3	14.8 434.6 156.6	1.6 12.4 7.2		11.6 560.0 88.9
433	10	3.6 6.2 Avg.	6.0 180.0 94.2	0.0 4.0 0.7	110.0 460.0 282.7(9)	66.0 530.0 320.5	0.5 3.3 1.6	0.3 14.4 2.9		1000.0 21600.0 5876.0
434	9	3.6 6.3 Avg.	5.0 575.0 138.0	0.0 5.0 1.0	82.0 400.0 264.5(8)	65.0 510.0 293.8	0.2 3.8 2.1	0.3 4.0 1.8		1000.0 16800.0 4172.2

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Total Manganese (mg/l)	Total Aluminum (mg/l)	Flow (cfs)
439	Min.	6.9	2.0	5.0	98.0	25.0	0.5	0.1		2.0
	Max.	7.2	73.0	154.0	184.0	100.0	3.2	1.4		858.0
	Avg.		25.0	72.3	148.4(5)	50.7	1.1	0.8		257.1
441	Min.	3.1	6.0	0.0	68.0	40.0	2.0	0.4		402.0
	Max.	5.6	650.0	50.0	472.0	570.0	16.4	2.5		21300.0
	Avg.		177.7(7)	7.1(7)	224.7(7)	256.0	6.0	1.4(7)		5897.8
444	Min.	3.1	0.0	0.0	94.0	79.0	2.2	0.2		5.9
	Max.	7.5	535.0	82.0	820.0	1500.0	22.2	6.0		900.0
	Avg.		170.1	22.7	424.8(8)	646.9	11.2	2.0		147.4
445	Min.	6.4	0.0	26.0	78.0	51.0	0.2	0.0		1.7
	Max.	8.1	37.0	130.0	390.0	900.0	2.7	0.1		1800.0
	Avg.		12.2	67.5	220.4(5)	347.2	0.7	0.1		397.9
447	Min.	5.5	5.0	3.0	58.0	32.0	0.1	0.0		500.0
	Max.	8.8	34.0	14.0	232.0	77.0	4.2	1.4		6940.0
	Avg.		21.7	7.3	106.0(8)	52.1	1.1	0.4		2027.1

*() Indicates the number of samples used in averages when other than the maximum.

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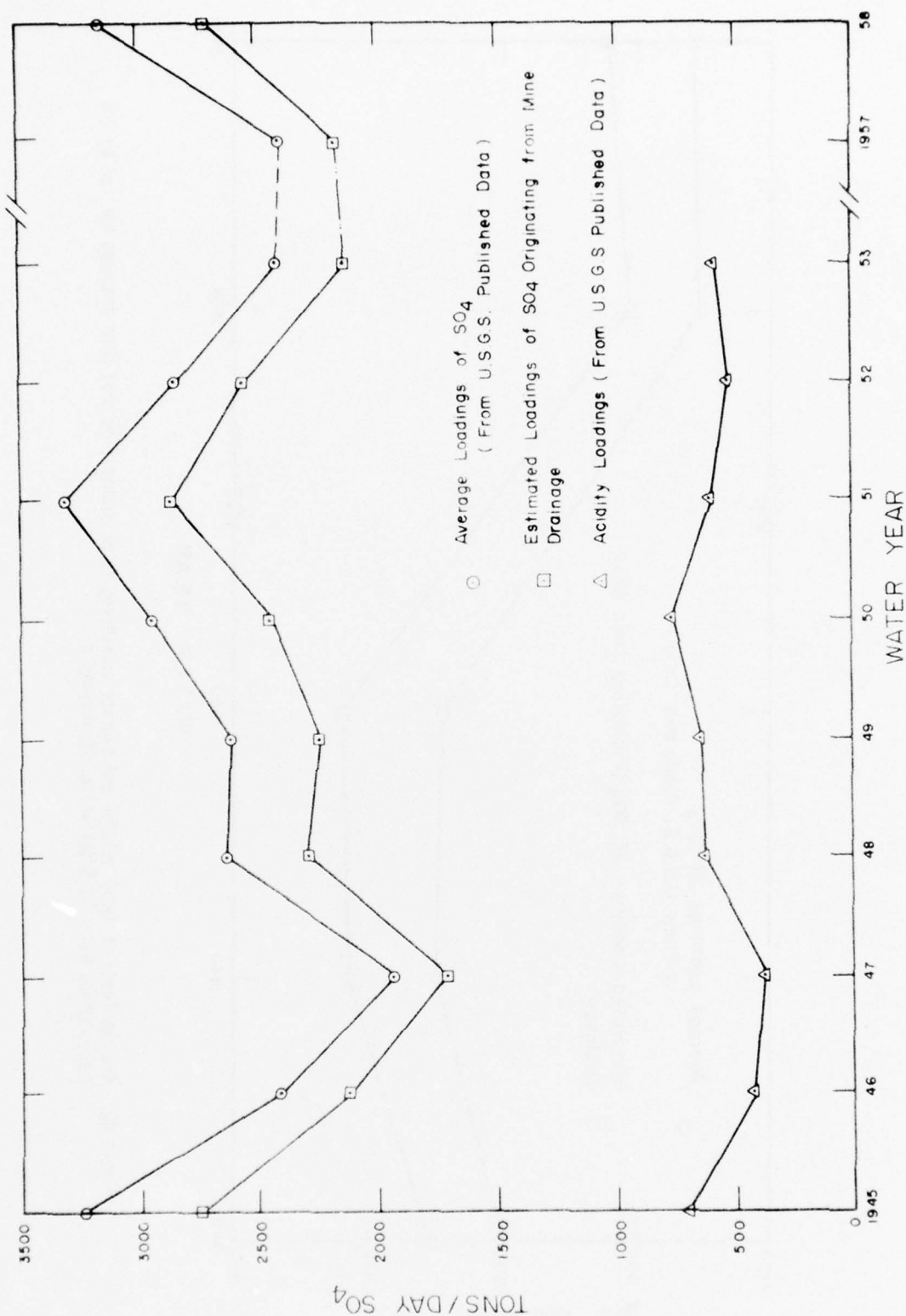


Figure 41. Average loads of acidity, total sulfate and sulfite considered to originate from coal mine drainage carried by the Monongahela River at Charlestown, Pennsylvania.

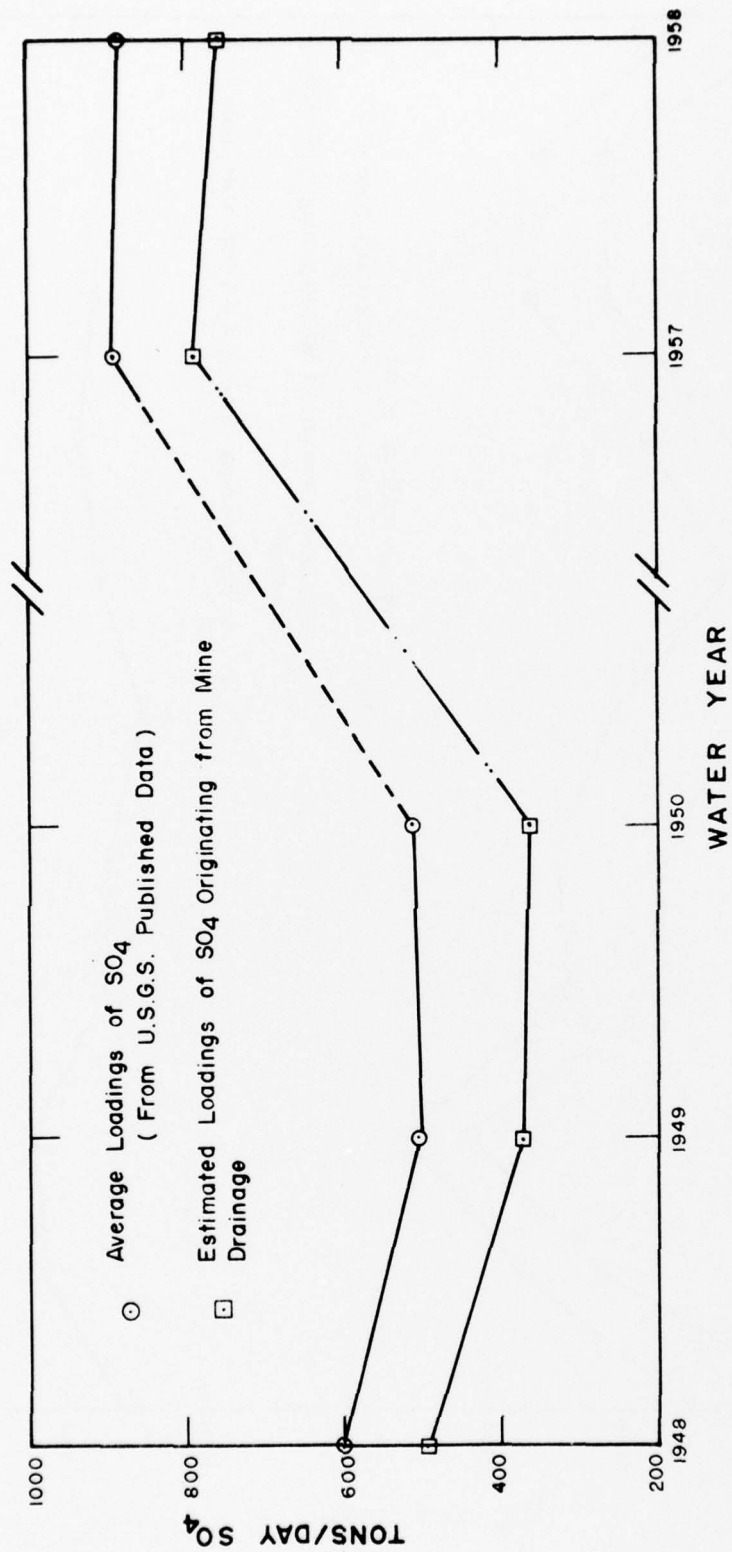


Figure 42. Average loads of total sulfate and sulfate considered to originate from coal mine drainage carried by the Youghiogheny River at Sutersville, Pennsylvania.

Beaver River Basin

Description

The Beaver River basin is located in northeastern Ohio and northwestern Pennsylvania. The Beaver River is formed by the confluence of the Mahoning River and Shenango River near New Castle, Pennsylvania (Fig. 43). It flows in a southerly direction for about 21 miles, then enters the Ohio River at Beaver, Pennsylvania, which is 25 river miles below Pittsburgh, Pennsylvania. The total drainage area of the basin is 3,145 square miles encompassing parts of 13 counties in the two states. Principal tributaries to the Beaver River are the Mahoning and Shenango Rivers and Connoquenessing, Slippery Rock, and Neshannock Creeks.

The Pennsylvania portion of the Beaver River basin, parts of seven counties, is contained within the Appalachian Region. The Ohio portion of the Beaver River basin is not included in the Appalachian Region.

The Beaver River basin is situated in the Appalachian Plateaus physiographic province. The topography of the northern and western portions of the basin has been changed by the continental ice sheets, which rounded the hills and filled most of the bedrock valleys with thick deposits of glacial sediments. The southeastern part of the basin drained by Connoquenessing Creek is unglaciated and is dissected plateau.

Recoverable bituminous coal reserves underlie three-fourths of the Beaver River basin and are estimated to be in excess of three billion tons. Of this total more than two-thirds of the reserve is in the Pennsylvania portion of the basin.

Coal production has been reported in all counties of the basin that contain reserves. Production for 1965 exceeded four million tons. Surface mining accounted for virtually all of the coal produced. (Brant and DeLong, 1960; Ohio Department of Industrial Relations, 1965).

Mine Drainage Sources and Their Effect on Stream Quality

A 1963 survey conducted by the State of Pennsylvania (Pennsylvania Department of Health, 1965) located 935 active and inactive surface and underground mines. Of this total, 590 were surface mines, but 67 percent of the acid discharge measured originated in the 304 abandoned underground mines that were inventoried. Most of the remaining acid discharged originated in active strip mines.

Sulfate loading data obtained during the 1966 stream survey indicate that in the order of 165 tons/day of acidity originates in surface and underground sources in the Slippery Rock Creek watershed. It is estimated that of the 165 tons/day of acidity formed perhaps 50 tons/day enters unneutralized into streams in the watershed.

The Beaver River basin contains about 108 miles of streams polluted by acid mine drainage (Fig. 43). The most seriously affected watershed in the basin is Slippery Rock Creek, which contains about 93 miles of acid polluted streams.

The Slippery Rock Creek drainage basin has had a long history of pollution resulting from mine drainage. Extensive deep mine activities were initiated in the early 1900's. Beginning with the early 1940's the deep mining activity was followed by the onslaught of literally hundreds of strip mines. A 1963 survey of the Slippery Rock Creek watershed showed 935 active and inactive operations. Of this total, 590 of the operations were strip mines.

The large number of mines in the Beaver River basin led to adverse effects on stream quality, but until 1958 the lower reaches of the stream were protected by the alkaline discharges from a limestone plant. When this plant ceased operations in late 1957, the stream became acid from its headwaters to the confluence with the South Branch. On July 12, 1964 an extremely heavy rainstorm fell in the upper, now acid, portion of the creek. This flushed out acidity from swamps, strip mine pits, ponds, and even from the creek itself. As a result of this large amount of acidity moving downstream, two million fish were killed (Pennsylvania Department of Health, 1965).

During the 1966 survey, the North Branch of Slippery Rock Creek discharged an average net acidity load of 6 tons/day (Sta. 482). The pH ranged from 3.8 to 5.0. The South Branch of Slippery Rock Creek (Sta. 483), was alkaline during the survey, but carried high concentrations of some mine drainage indicators. Further downstream (Sta. 481) the average acidity load in Slippery Rock Creek had decreased to an average level of 5 tons/day in excess of the alkalinity. Above the confluence of Wolf Creek (Sta. 480) Slippery Rock Creek showed further decreases in the net acidity.

Wolf Creek above Grove City receives some mine drainage, but this is rapidly neutralized during travel downstream. At the mouth of Wolf Creek (Sta. 477), the net alkalinity load averaged 20 tons/day and the minimum pH was 6.9. The alkalinity carried by Wolf Creek neutralizes any acidity in Slippery Rock Creek at that point and the net alkalinity at sampling station 476 was 35 tons/day.

Muddy Creek also receives some acid mine drainage, but during the survey, Muddy Creek exhibited a pH range of 6.3 to 7.4 at its mouth and the average alkalinity concentration exceeded the acidity (Sta. 484).

Near its mouth (Sta. 175) Slippery Rock Creek had a pH range of 6.9 to 7.6, an average net alkalinity load in excess of 37 tons/day.

Little Connoquenessing Creek receives some acid mine drainage. Alkalinity loads always exceeded acidity loads during the study period, but some mine drainage was indicated by the high concentrations of iron, sulfates, and hardness (Sta. 471).

Mine drainage problems in the Beaver River basin are not limited to the Pennsylvania portion of the basin. There are several streams in Mahoning County, Ohio, though not continuously polluted by mine drainage, which have experienced washouts of acid mine water. A washout, occurring in January 1965, resulting in a fish kill of 1,600 along a tributary to Meander Creek.

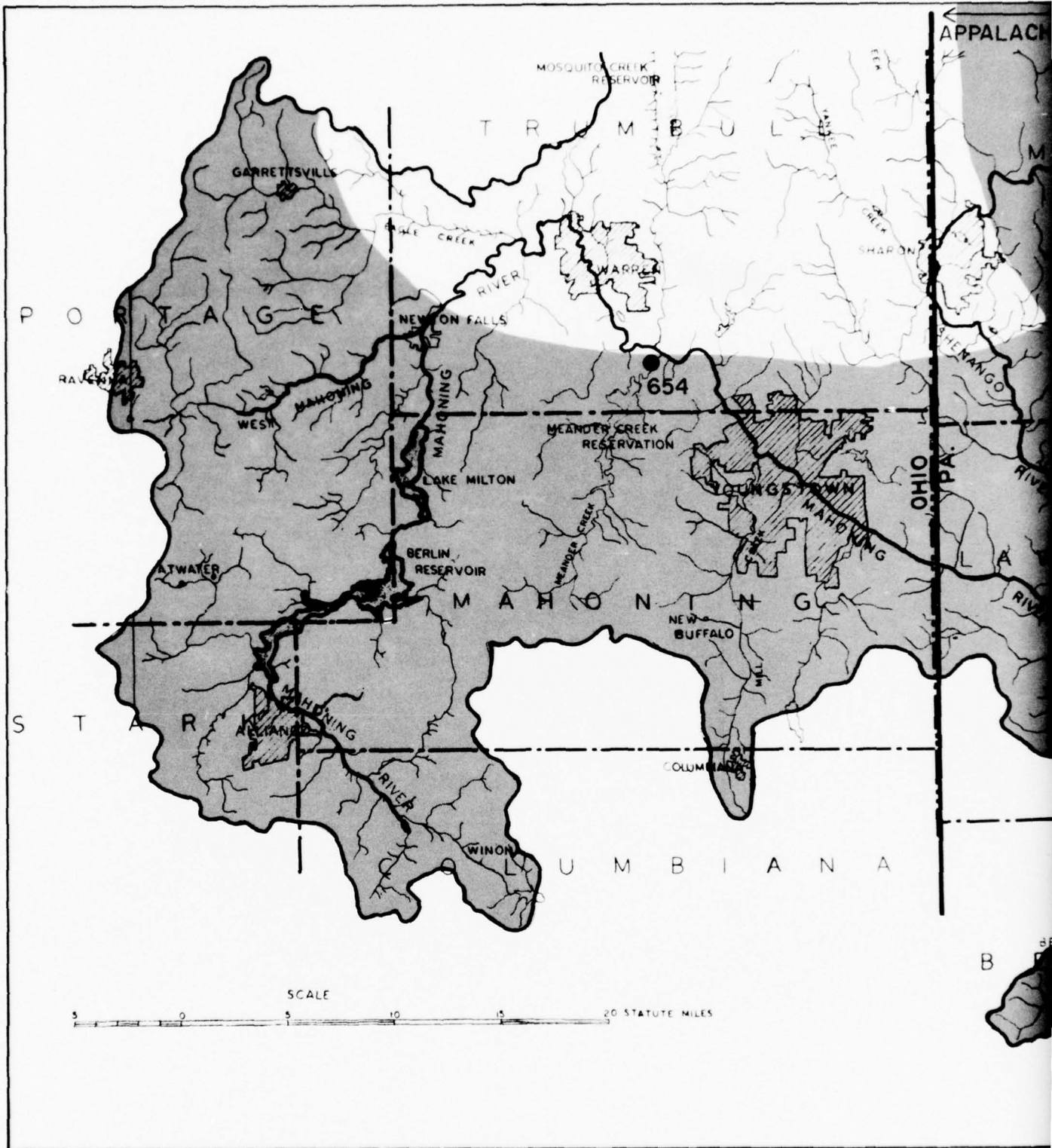
Table 11 - Water Quality Data, Beaver River basin

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Total Manganese (mg/l)	Total Aluminum (mg/l)	Flow (cfs)
471	9	6.5 7.6 Avg.	0.0 34.0 9.3	17.0 53.0 31.3	90.0 326.0 205.1	50.0 560.0 188.0(8)*	0.0 4.2 1.3	0.2 1.4 0.8	0.0 3.0 1.0(6)	1.9 340.0 79.0
475	9	6.9 8.3 Avg.	0.0 16.0 4.3	21.0 92.0 62.8	114.0 253.0 196.9	82.0 165.0 132.4	0.0 4.2 0.9	0.0 2.3 0.7	0.4 6.0 1.5(6)	0.4 2240.0 513.4
476	9	6.6 7.8 Avg.	0.0 21.0 6.9	21.0 75.0 45.4	114.0 233.0 176.7	72.0 175.0 127.9	0.0 2.9 0.7	0.0 2.5 0.9	0.0 6.1 1.6(6)	0.0 2460.0 586.9
477	6	6.8 7.8 Avg.	0.0 25.0 9.8	48.0 79.0 62.0	130.0 236.0 164.8	48.0 140.0 94.8	0.3 0.7 0.5	0.2 0.8 0.4	0.4 1.0 0.6(3)	57.0 222.4 109.5
478	9	7.1 8.5 Avg.	0.0 29.0 10.9	36.0 111.0 68.6	112.0 281.0 184.7	38.0 160.0 100.5(8)	0.0 2.4 0.9	0.3 1.3 0.7	0.0 7.5 1.6(6)	22.0 540.0 114.4
479	3	6.9 7.0 Avg.	15.0 49.0 27.7	22.0 38.0 31.3	66.0 128.0 104.7	33.0 80.0 60.3	0.4 2.1 1.1	0.6 1.3 1.0		55.0 290.0 165.0
480	9	4.3 7.2 Avg.	0.0 55.0 19.8	0.0 45.0 15.4	128.0 279.0 201.9	85.0 240.0 176.1	0.3 1.8 0.9	1.0 3.1 2.1	0.5 6.9 2.9(6)	16.7 448.2 149.6
481	3	6.6 7.0 Avg.	11.0 27.0 16.7	8.0 15.0 10.7	116.0 180.0 150.7	90.0 140.0 120.0	0.4 1.0 0.7	1.3 2.1 1.7		185.0 356.0 288.7

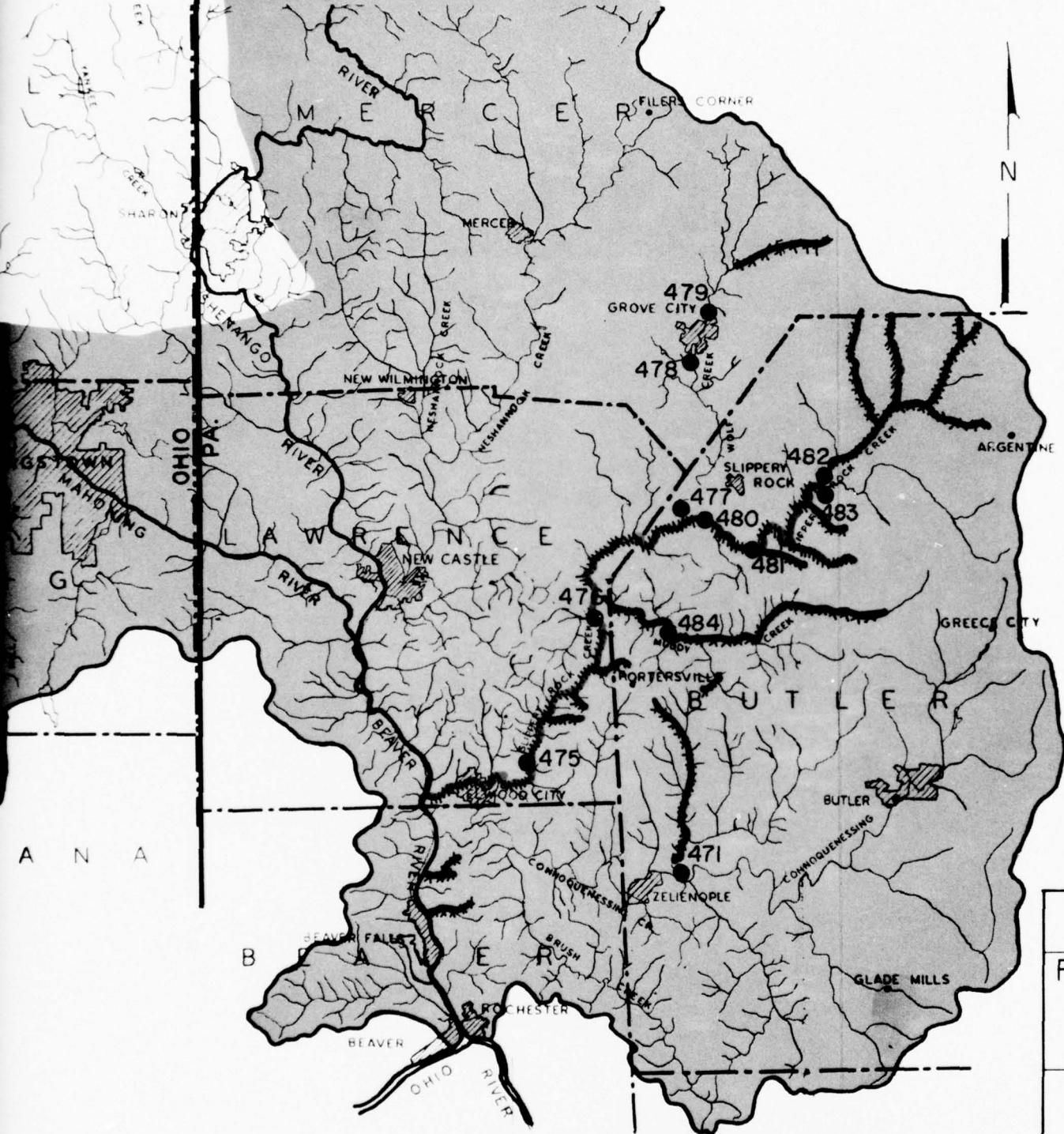
Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total			Flow (cfs)
							Iron (mg/l)	Manganese (mg/l)	Aluminum (mg/l)	
L82	Min.	2.7	24.0	0.0	132.0	110.0	0.2	1.0	1.8	8.9
	Max.	5.0	153.0	10.0	312.0	390.0	40.0	3.4	14.0	164.0
	Avg.		60.1	3.8	217.1	226.1	8.0	2.6	7.8(6)	64.5
L83	Min.	6.7	0.0	22.0	116.0	73.0	0.2	1.0	0.1	2.3
	Max.	7.2	22.0	78.0	333.0	270.0	7.9	3.1	17.2	100.0
	Avg.		7.0	39.2	223.6	172.4	1.7	1.4	3.1(6)	31.3
L84	Min.	6.1	0.0	8.0	110.0	77.0	0.1	0.4	0.0	2.0
	Max.	7.4	28.0	67.0	358.0	310.0	1.3	3.4	2.5	330.0
	Avg.		11.0	24.9	215.4	182.7	0.6	1.7	1.1(6)	81.3
654	Min.	7.8	0.0	32.0	113.0	115.0	0.1	0.1	0.2	0.1
	Max.	10.6	3.0	245.0	176.0	156.0	0.4	5.2	2.2	12.0
	Avg.		0.5	117.8	140.2	131.8	0.3	1.2	1.1(3)	3.5

*(8) Indicates the number of samples used in averages when other than the maximum.

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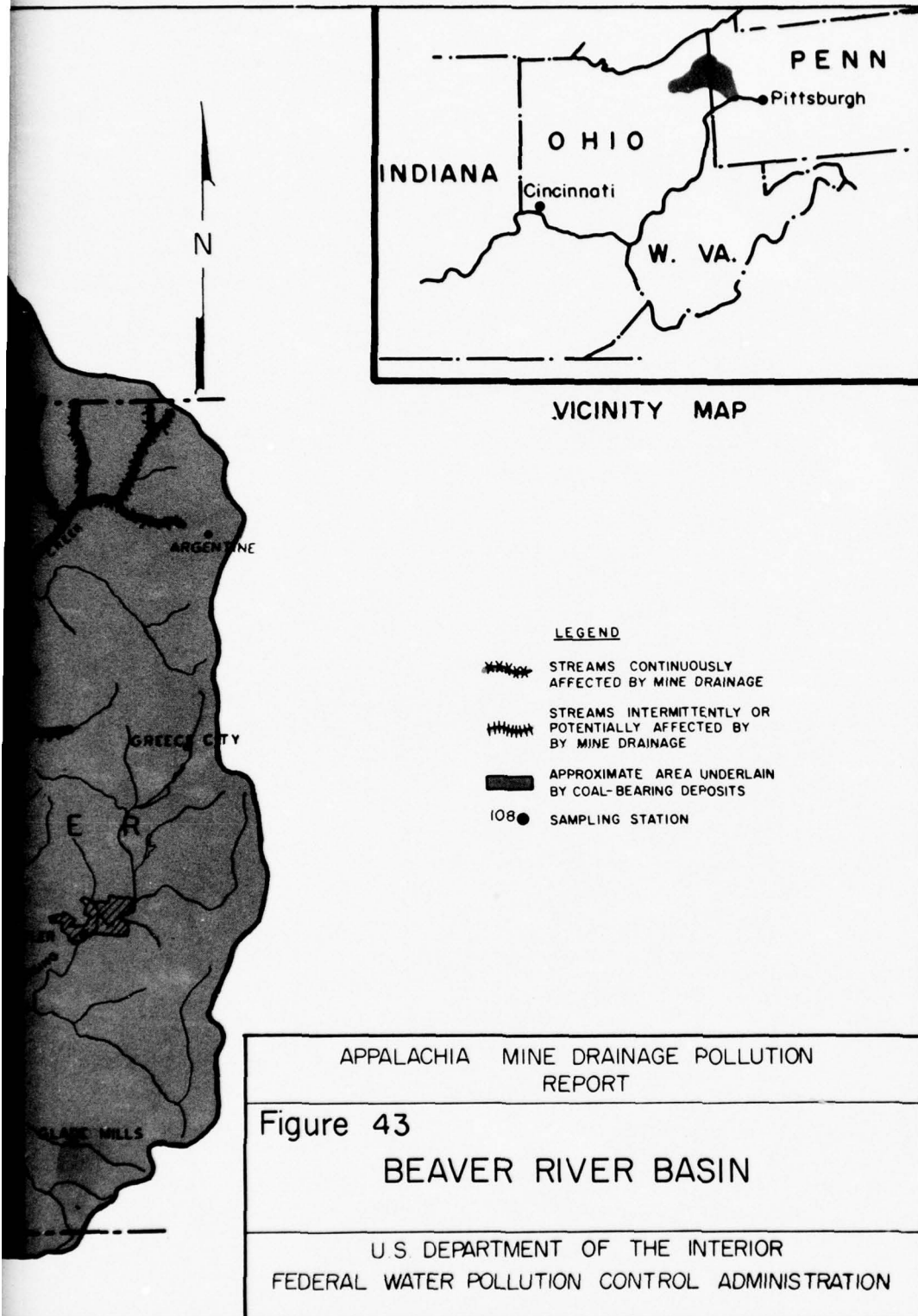


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Muskingum River Basin

Description

The Muskingum River basin lies in the eastern part of Ohio. It is bounded by the Scioto River drainage on the west, Lake Erie drainage on the north, and the Ohio River minor tributary drainage on the east and south. The Muskingum River is formed by the junction of its two principal tributaries, the Tuscarawas and Walhonding Rivers, at Coshocton near the center of the basin (Fig. 44). The Muskingum flows south for about 110 miles entering the Ohio River at Marietta, Ohio, 172 miles below Pittsburgh, Pennsylvania. The total drainage area of the basin is 8,040 square miles, about 20 percent of the land area of the State, and covers all or part of 27 counties. About half the area of the Muskingum basin is located in the Appalachian Region. The counties or portions of counties (11 in number) making up the western and northern boundaries of the basin are excluded.

The northern and western portions of the watershed were covered by Pleistocene age glaciers. The line of glaciation generally trends east to west from Canton to Loudonville, and thence almost directly south leaving the basin in Perry County. The glaciated area is characterized by gently rolling to flat topography. The unglaciated area is generally rugged and well dissected by drainage.

Bituminous coal reserves in the Muskingum basin are present in 21 of the 27 Ohio counties that are wholly or partly contained in the watershed, amounting to 80 percent of the area. Coal production has been reported from all but one of the 21 counties containing reserves. Recoverable coal reserves in the Muskingum River basin portion of these counties is estimated at over eight billion tons.

The Muskingum basin has a long history of coal production, and prospects for long-term continued production are excellent in view of recent industrial expansion in the area. Six of the basin counties had a cumulative coal production of over 100 million tons during the period 1800-1958. Production in 1965 in the watershed amounted to nearly 19 million tons, about 70 percent by surface mining methods (Brant and DeLong, 1960; Ohio Department Industrial Relations, 1965).

Mine Drainage Sources and Their Effect on Stream Quality

Although some mine drainage pollution occurs in each of the coal-producing counties of the basin, Tuscarawas, Coshocton, Muskingum, and Perry Counties are the most seriously affected in terms of number of streams and total length of streams affected

(Fig. 44). With very minor exceptions, all affected streams in the basin are within the Appalachian Region. A total of over 500 miles of streams in the watershed are considered to be polluted by mine drainage (Table 12).

Table 12 - Lengths of Streams Polluted by Mine Drainage
Muskingum River Basin

	Drainage Area (square miles)	Continuously Polluted (miles)	Inter- mittently Polluted (miles)	Total (miles)
Muskingum River	8038			
Tributaries		244	59	303
Tuscarawas River	2590			
Tributaries		154	34	188
Walhonding River	2252			
Tributaries		16	15	31
		414 +	108 =	522

On the basis of a detailed study of the McCluney Creek watershed in Perry County, Ohio, (Fig. 44) and general knowledge of the Muskingum basin, it is estimated that there are 200 significant pollution sources originating from inactive and active coal mines. There are 29,000 acres of unreclaimed surface mined land in the Muskingum basin.

Data obtained during 1966 indicate that about 500 tons/day of mine drainage acidity is formed in surface and underground locations in the Muskingum basin. It is estimated that of the 500 tons/day of acidity formed perhaps 400 tons/day enters unneutralized into streams in the basin.

Water quality data gathered during 1966 shows that, although many smaller streams in the Muskingum watershed are affected, the large dilution and neutralization factors provided keeps mine drainage effects in the principal streams to a minimum, and other industrial pollution largely masks the quality changes caused by mine drainage.

The following fish kills resulting from acid mine drainage were reported in the Muskingum River basin during 1966:

Date	County	Watershed	Number of Fish Killed
8/12/66	Perry	Jonathan Creek	5,000
8/21/66	Coshocton	Mill Creek	3,061
8/31/66	Tuscarawas	Sugar Creek	50,670
9/22/66	Muskingum	Muskingum River	20,860

Most of the coal mine drainage flowing into the Tuscarawas River enters in the reach between Massillion and Newcomerstown. Industrial pollution originating in the Akron area affects the Tuscarawas River to such a degree that the influence of the mine drainage that enters the river below Massillion is not easily recognizable. The effect of mine drainage is, however, reflected in loadings of mine drainage pollution indicators. The average sulfate loading was 142 tons/day at station 719 above Massillion and 250 tons/day at station 727 above Newcomerstown. The average iron loadings were 0.3 tons/day and 2 tons/day at these respective stations.

The small amount of mine drainage entering the Walhonding River is contributed by tributaries entering in the lower 10 miles of the river. These sources and tributaries entering the Muskingum immediately below Coshocton do not significantly affect the quality of the Muskingum, but are evidenced by increased loadings of mine drainage indicators, such as sulfate, hardness, and iron.

In the lower Muskingum basin, Moxahala Creek and its tributaries in Perry and Muskingum Counties are the most seriously polluted streams from acid mine drainage in the Muskingum basin. Ninety miles of streams in this small watershed are affected. A 1963 survey showed Moxahala Creek to be highly acidic over most of its length and discharging 8 tons/day of acidity to the Muskingum River. Readings of pH as low as 2.7 were observed in stream waters during the survey. Limited field work conducted during 1966 indicates there may be more than 200 significant point sources of mine drainage polluting the streams of the Moxahala watershed.

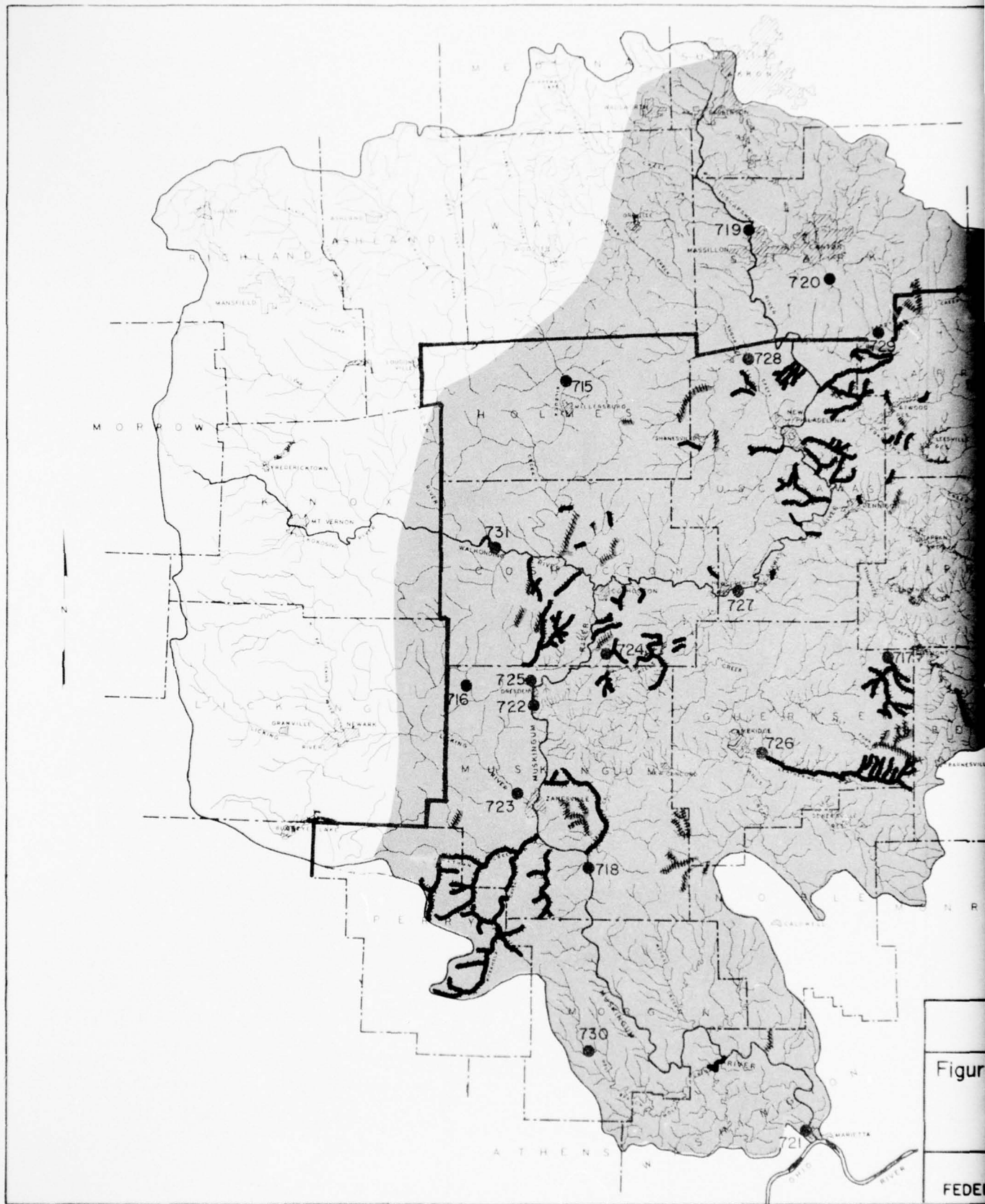
Table 13 - Water quality data, Muskingum River basin

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Total Manganese (mg/l)	Total Aluminum (mg/l)	Flow (cfs)
1715	9	7.3	0.0	93.0	126.0	52.0	0.2	0.2	0.7	18.1
	Min.									
	Max.	7.7	10.0	201.0	228.0	136.0	3.8	1.0	3.1	687.0
	Avg.		1.3(8)*	161.4(8)	162.1(8)	67.9	1.7	0.5	1.6(6)	211.0
1716	9	7.1	0.0	69.0	106.0	9.0	0.4	0.1	0.6	10.0
	Min.									
	Max.	7.6	24.0	194.0	156.0	35.0	0.7	0.3	1.3	38.0
	Avg.		4.1	97.9	132.2	21.3(8)	0.6	0.2	0.9(6)	21.0
1717	12	6.4	0.0	26.0	49.0	25.0	0.4	0.1	0.7	0.0
	Min.									
	Max.	7.7	28.0	148.0	236.0	105.0	5.9	7.2	1.3	150.4
	Avg.		10.6	83.4	141.5	67.7	1.3	1.4	1.0(5)	45.1
1718	9	6.8	0.0	74.0	327.0	160.0	1.0	0.2	1.6	890.0
	Min.									
	Max.	8.0	39.0	120.0	432.0	240.0	2.5	3.3	3.4	3027.0
	Avg.		12.7	100.1	390.2	190.3	1.6	1.3	2.3(6)	1573.6
1719	14	6.3	16.0	79.0	295.0	35.0	0.2	0.0	0.4	75.0
	Min.									
	Max.	8.3	129.0	216.0	3000.0	2500.0	3.6	0.3	19.6	847.0
	Avg.		64.5	145.3	1752.4	443.8(13)	1.0(13)	0.1(13)	4.3(6)	254.9
1720	15	7.0	0.0	98.0	198.0	20.0	0.0	0.3	0.0	62.3
	Min.									
	Max.	7.8	99.0	302.0	474.0	500.0	5.0	1.4	1.6	500.0
	Avg.		13.4	302.0	292.9	240.9	2.1	0.9	0.9(7)	144.1
1721	9	6.9	0.0	89.0	222.0	132.0	0.2	0.1	0.5	980.0
	Min.									
	Max.	7.9	45.0	127.0	428.0	215.0	1.2	0.6	2.2	2600.0
	Avg.		11.9	105.6	346.8	179.8	0.5	0.3	0.9(6)	1647.2
1722	9	7.0	0.0	12.0	126.0	110.0	0.5	0.3	1.0	800.0
	Min.									
	Max.	8.6	32.0	118.0	428.0	220.0	2.3	1.2	2.0	2410.0
	Avg.		7.7	104.1	343.4	168.1	1.0	0.8	1.4(6)	1318.0

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Total Manganese (mg/l)	Total Aluminum (mg/l)	Flow (cfs)
1723	9	7.2 8.1 Avg.	0.0 43.0 10.8	16.0 187.0 140.0	133.0 420.0 216.2	56.0 425.0 107.8	0.4 1.4 0.9	0.2 1.1 0.5	0.0 2.2 1.0(6)	87.0 348.0 167.4
1724	9	6.7 7.5 Avg.	0.0 28.0 7.0	0.0 86.0 61.9	140.0 375.0 273.3	110.0 310.0 253.9	0.4 10.8 2.4	0.9 5.4 2.2	0.6 4.9 2.1(6)	30.0 264.0 77.8
1725	9	6.8 7.4 Avg.	0.0 82.0 18.4	47.0 89.0 73.9	140.0 263.0 199.8	60.0 223.0 122.8	0.2 1.8 0.6	0.2 13.8 2.9	0.5 2.0 1.2(6)	28.0 75.5 46.7
1726	4	6.9 7.1 Avg.	0.0 27.0 11.5	90.0 131.0 108.5	431.0 624.0 548.8	440.0 565.0 503.8	0.9 1.4 1.2	0.8 1.2 1.0	0.3 1.4 0.9(3)	0.0 0.0 0.0
1727	12	6.5 8.6 Avg.	0.0 68.0 17.9	41.0 150.0 80.5	242.0 804.0 516.4	110.0 320.0 194.6	0.5 3.9 2.2	0.8 2.0 1.3	0.7 5.2 2.0(5)	295.0 9800.0 2357.6
1728	14	6.9 8.2 Avg.	0.0 43.0 11.1	38.0 123.0 83.6	168.0 429.0 319.2	120.0 4750.0 572.7	0.4 2.0 1.0	0.4 12.2 3.3	0.1 2.0 1.1(7)	9.1 830.0 145.8
1729	15	6.9 8.1 Avg.	0.0 54.0 10.5	23.0 137.0 85.2	83.0 440.0 211.1	68.0 200.0 123.9	0.2 4.5 2.1	0.2 1.5 0.7	0.7 2.2 1.4(7)	28.0 1420.0 272.5
1730	8	7.5 8.2 Avg.	0.0 42.0 7.1	151.0 224.0 182.3	44.0 170.0 117.0	25.0 54.0 39.4	0.0 0.5 0.2	0.2 0.7 0.3	0.0 0.8 0.5(5)	0.1 12.3 3.1

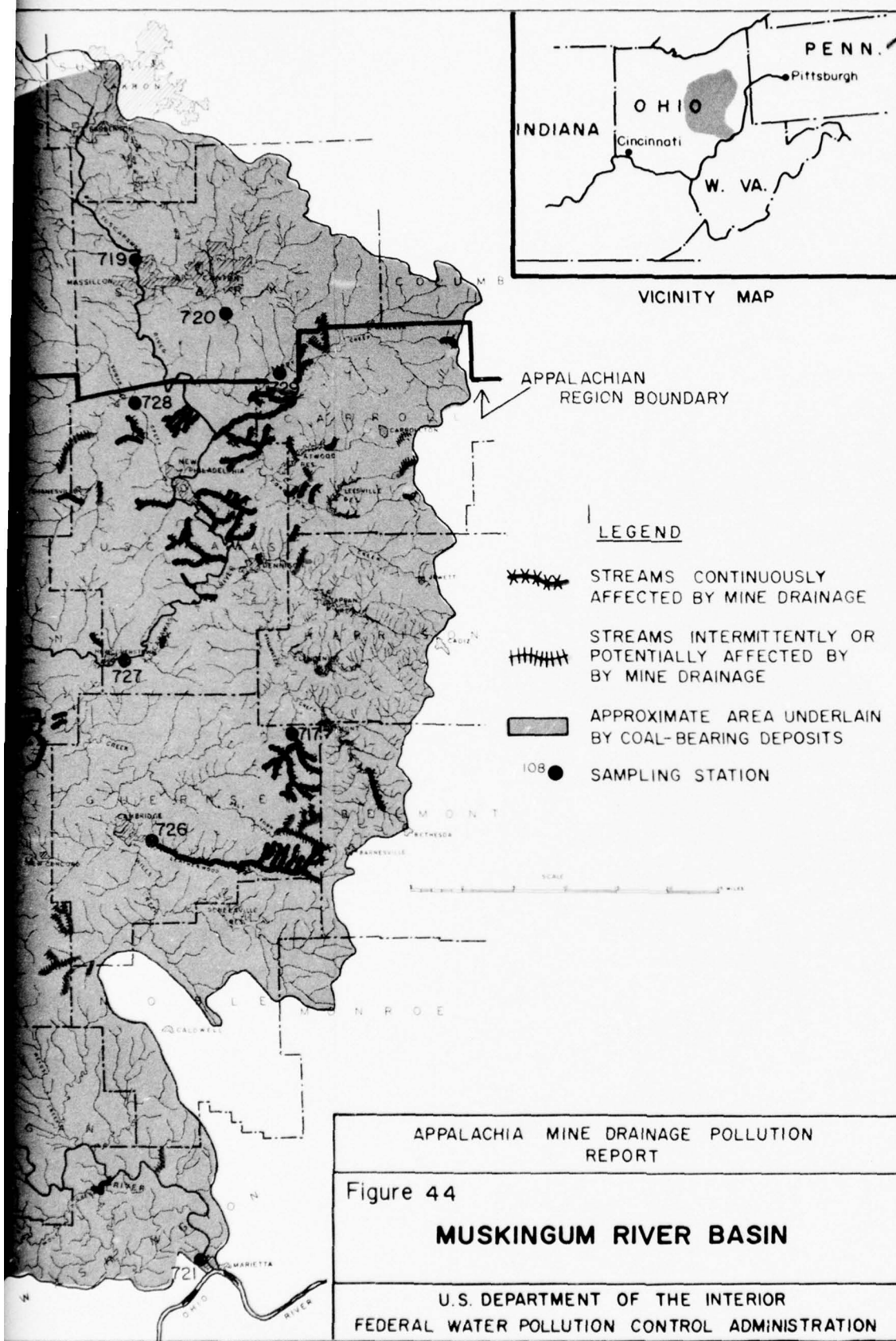
Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Total Manganese (mg/l)	Total Aluminum (mg/l)	Flow (cfs)
1731	9	7.1	0.0	105.0	106.0	40.0	0.2	0.0	0.6	281.0
		8.2	56.0	158.0	209.0	75.0	1.4	0.5	2.5	2480.0
			6.2	137.7	164.9	57.7	0.7	0.2	1.2(6)	941.0

*(8) Indicates the number of samples used in averages when other than the maximum.



Figure

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Hocking River Basin

Description

The Hocking River basin embraces an area of 1200 square miles located in the hill section of southeastern Ohio (Fig. 45). The basin is bounded on the north by the Muskingum River drainage basin, on the west by the Scioto River basin, and on the south by the Raccoon Creek, Leading Creek, and Shade River drainage basins. The basin includes portions of Fairfield, Perry, Hocking, Morgan, Athens, Meigs, and Washington Counties. Of the counties in the Hocking River basin, all but Fairfield County, in the northwest corner of the watershed, are in the Appalachian Region.

With the exception of the uppermost part in Fairfield, Perry and Hocking Counties, the Hocking basin lies in the unglaciated portion of Ohio. Generally, the valleys are narrow and the hillsides are steep and abrupt. The divides are ridge-like, separating streams arranged generally in a dendritic pattern. The Hocking River heads in Fairfield County in the northwestern portion of the basin. The stream extends approximately 95 miles in a relatively straight line in a southeastward direction to its confluence with the Ohio River, about 15 miles below Parkersburg, West Virginia. The river has an average gradient of 4.6 feet per mile. Principal tributaries to the Hocking watershed include Rush Creek, Sunday Creek, Monday Creek, and Federal Creek.

Bituminous coal reserves in the Hocking River basin are present in five of the six counties that make up the watershed, amounting to three-quarters of the area. Coal production has been reported in all of the counties containing reserves. Production in 1962 amounted to more than 900,000 tons and increased to over 1.6 million in 1965. Surface mine operations accounted for approximately 80 percent of the total coal production figures in 1965.

The recoverable reserve of coal within the boundaries of this drainage area is estimated at over one billion tons. (Brant and DeLong, 1960; Ohio Department of Industrial Relations, 1965). This tonnage represents substantial potential for continued and expanded coal production in the Hocking River basin.

Mine Drainage Sources and Their Effect on Stream Quality

During a detailed study of 74 square miles in the Sunday Creek watershed (Fig. 45), 20 mine drainage sources were examined and 15 drainages were sampled. The total number of sources is not known. There are presently 4,000 acres of unreclaimed surface-mined land in the basin.

Calculation of sulfate loadings for 1955-1959, 1962, 1963 and 1965 (Fig. 46) at Athens, Ohio, indicates that an average of about 335 tons/day of acidity are formed in the Hocking basin. Of this total, it is estimated that 200 tons/day enters streams in the basin unneutralized.

The Hocking River basin contains 364 miles of streams significantly polluted by coal mine drainage, 223 miles of which are continuously polluted and 141 miles of which are intermittently polluted. The principal problem areas are found in Athens, Hocking, and Perry Counties (Fig. 45).

Major tributaries to the Hocking River polluted by coal mine drainage are Rush Creek, Monday Creek, Sunday Creek, and Federal Creek. At its midpoint (Sta. 696) Monday Creek carried an acidity load of 5.6 tons/day, had a pH range of 3.1 to 3.6, and had high concentrations of sulfate, metals and hardness. At its mouth (Sta. 690) the acidity load in Monday Creek increased to 19 tons/day, the pH ranged from 2.8 to 3.3, and other mine drainage indicators were present in high concentrations.

At its confluence with Sunday Creek (Sta. 698), the West Branch of Sunday Creek carried an acidity load of 4.2 tons/day, exhibited a pH range of from 2.9 to 4.2, and had high concentrations of sulfate, metals, and hardness. Sunday Creek carried an acidity load of 13 tons/day at its mouth (Sta. 691) and had high concentrations of mine drainage indicators.

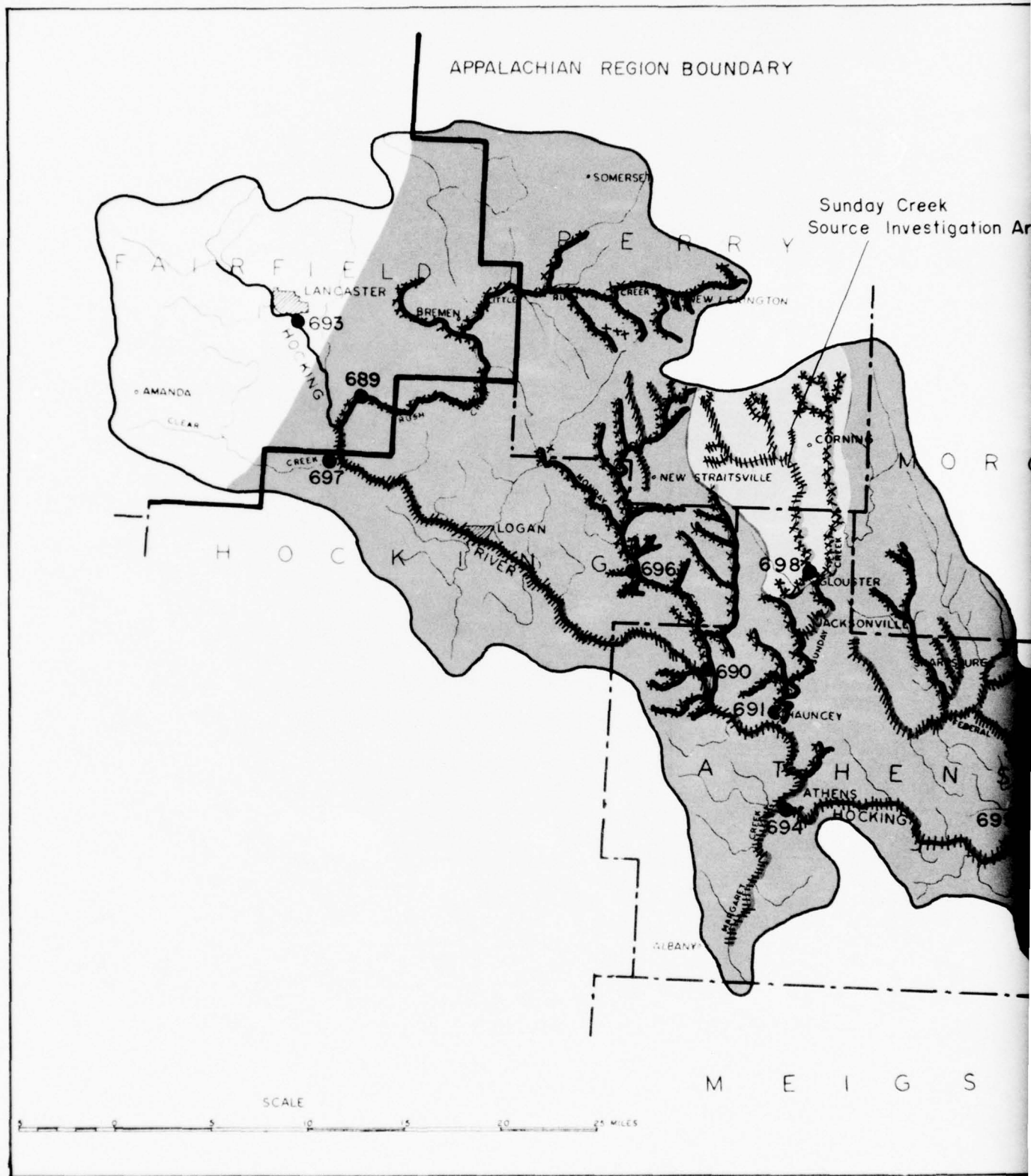
Rush and Federal Creeks receive mine drainage throughout their watersheds, but are alkaline at their mouths. The level of mine drainage pollution in these streams is indicated by the concentrations of sulfate, metals and hardness as measured at stations 689 and 699 (Fig. 45).

Table 14 - Water quality data, Hocking River basin

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Total Manganese (mg/l)	Total Aluminum (mg/l)	Flow (cfs)
689	Min.	5.8	0.0	10.0	75.0	75.0	0.2	1.6	0.0	36.0
	Max.	7.4	35.0	72.0	545.0	450.0	6.6	13.8	11.1	870.0
	Avg.		11.0	39.2	324.0	243.3	2.1	8.0	4.4	185.3
690	Min.	2.8	175.0	0.0	219.0	260.0	4.8	8.3	25.7	8.0
	Max.	3.3	597.0	0.0	1480.0	875.0	43.2	12.2	138.9	43.5
	Avg.		438.8	0.0	571.8	572.5	20.2	10.1	64.5	16.6
691	Min.	2.6	0.0	0.0	110.0	95.0	3.5	0.0	0.9	10.7
	Max.	6.2	712.0	32.0	780.0	1175.0	168.0	13.8	86.2	90.0
	Avg.		400.3	5.3	562.0	503.3	64.9	9.0	44.8	26.1
693	Min.	6.5	0.0	55.0	58.0	14.0	0.4	0.0	0.0	10.0
	Max.	7.9	9.0	296.0	290.0	120.0	7.6	0.3	10.6	304.0
	Avg.		1.5	223.3	180.2	74.8	2.2	0.2	4.3	62.1
694	Min.	6.6	0.0	30.0	104.0	80.0	0.3	1.3	0.9	92.0
	Max.	7.6	28.0	113.0	450.0	340.0	4.8	13.8	20.7	7600.0
	Avg.		5.3	74.7	368.0	236.7	1.7	5.1	5.3	1398.3
695	Min.	6.4	0.0	24.0	94.0	85.0	0.3	0.2	1.5	120.0
	Max.	7.7	25.0	90.0	430.0	340.0	6.2	4.4	6.8	7500.0
	Avg.		6.8	71.5	307.8	201.7	1.7	1.0	3.2	1417.5
696	Min.	3.1	107.0	0.0	455.0	164.0	3.6	8.2	6.4	2.2
	Max.	3.6	364.0	0.0	1044.0	580.0	12.0	13.8	66.6	15.0
	Avg.		248.7	0.0	675.0	419.0	6.7	11.0	27.1	7.6

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Total Manganese (mg/l)	Total Aluminum (mg/l)	Flow (cfs)
697	Min.	7.0	0.0	84.0	64.0	24.0	0.2	0.0	0.0	13.0
	Max.	8.2	0.0	187.0	267.0	37.0	5.3	1.6	7.9	312.0
	Avg.		0.0	143.7	149.6(5)*	31.7	1.2	0.6	1.9	66.3
698	Min.	2.9	125.0	0.0	250.0	330.0	16.8	3.9	3.7	3.5
	Max.	4.2	446.0	0.0	945.0	1225.0	72.0	13.8	123.8	12.2
	Avg.		315.8	0.0	696.0	740.8	49.7	11.0	54.6	5.7
699	Min.	5.0	0.0	1.0	168.0	120.0	0.0	0.3	0.2	0.0
	Max.	7.7	100.0	142.0	620.0	265.0	1.0	3.3	6.7	110.0
	Avg.		23.5	86.2	323.8	210.8	0.6	1.3	3.5	18.6

*(5) Indicates the number of samples used in averages when other than the maximum.



BOUNDARY

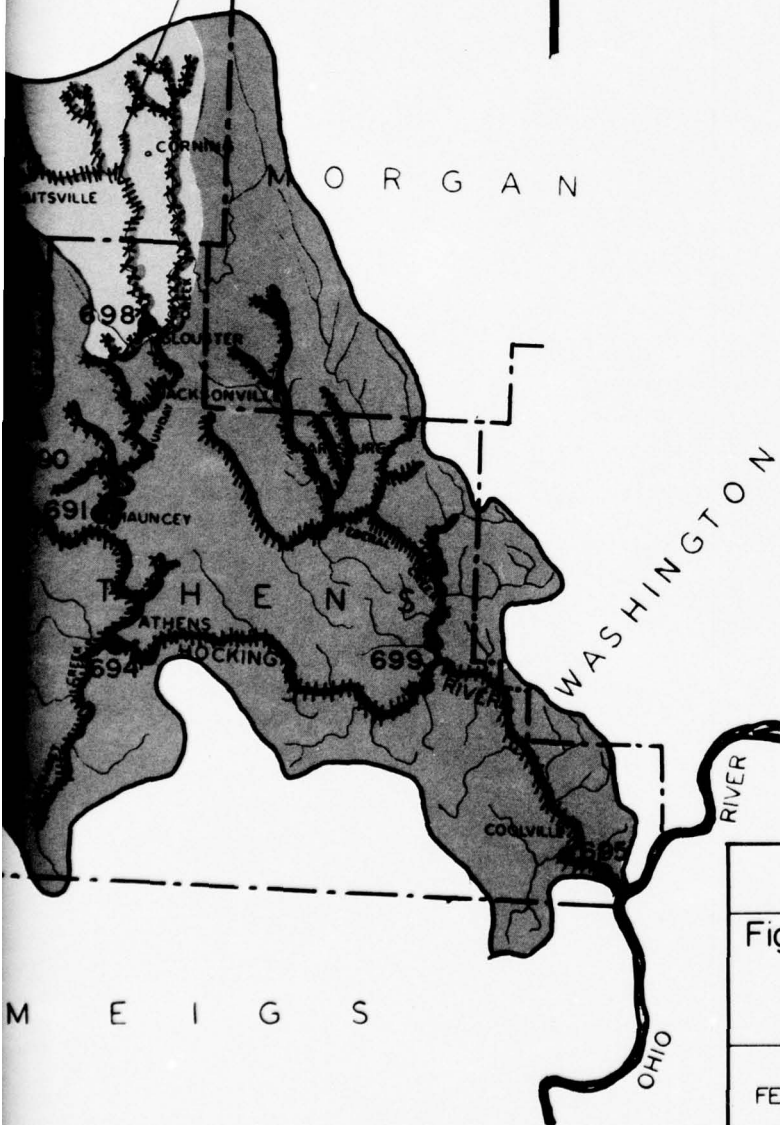
Sunday Creek
Source Investigation Area

R
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VICINITY MAP



LEGEND

- STREAMS CONTINUOUSLY AFFECTED BY MINE DRAINAGE
- STREAMS INTERMITTENTLY OR POTENTIALLY AFFECTED BY MINE DRAINAGE
- APPROXIMATE AREA UNDERLAIN BY COAL-BEARING DEPOSITS
- 108 ● SAMPLING STATION

APPALACHIA MINE DRAINAGE POLLUTION
REPORT

Figure 45

HOCKING RIVER BASIN

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

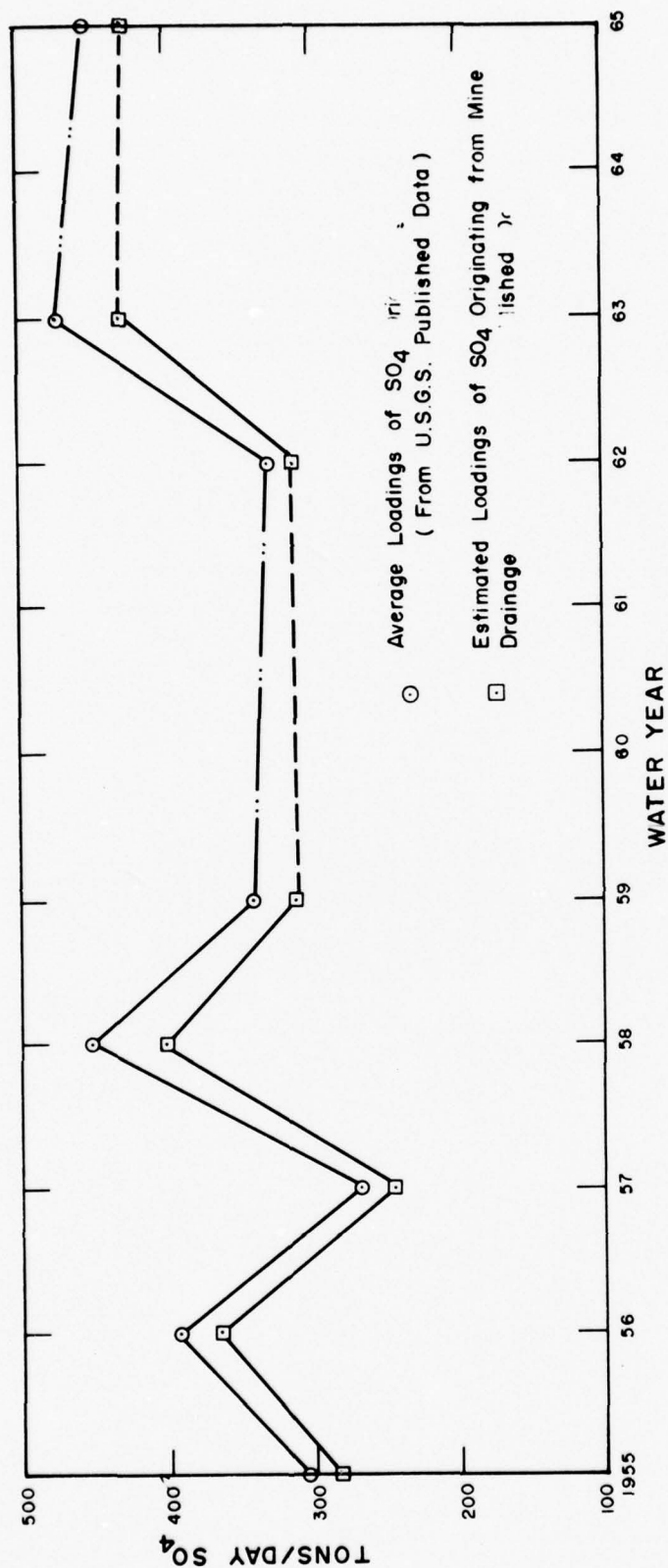


Figure 46. Average loads of total sulfate and sulfite considered to originate from coal mine drainage carried by the Hocking River at Athens, Ohio

Little Kanawha River

Description

The Little Kanawha River basin embraces 2,309 square miles of west-central West Virginia, lies entirely within the State, and entirely within Appalachia. The basin is bounded on the south by the Kanawha River basin, on the west by the Ohio River, on the north by the Middle Island Creek basin, and on the east by the Monongahela River basin. The basin contains all or part of 12 West Virginia counties (Fig. 47). The topography of the Little Kanawha basin is rugged throughout with elevations in the headwaters reaching approximately 2,200 feet. The normal pool elevation at the mouth of the basin is 572 feet, giving a total relief of about 1,630 feet.

Bituminous coal reserves are present in seven of the 12 counties which are wholly or partly contained in the basin (Fig. 47). The area underlain by mineable coal reserve amounts to about 60 percent of the total land area of the watershed. The recoverable coal reserve of the Little Kanawha River basin portion of these counties is estimated to be about two billion tons.

Although the watershed contains an appreciable coal reserve, the resource has not been extensively tapped. The coal removed over the years in this area has been mostly for domestic uses. Development of the reserves has been hindered by mining difficulty, high sulfur content, and variable thickness. Coal production in 1965 amounted to over one million tons, predominantly from underground mining in Gilmer County (West Virginia Department of Labor and Industry, 1965).

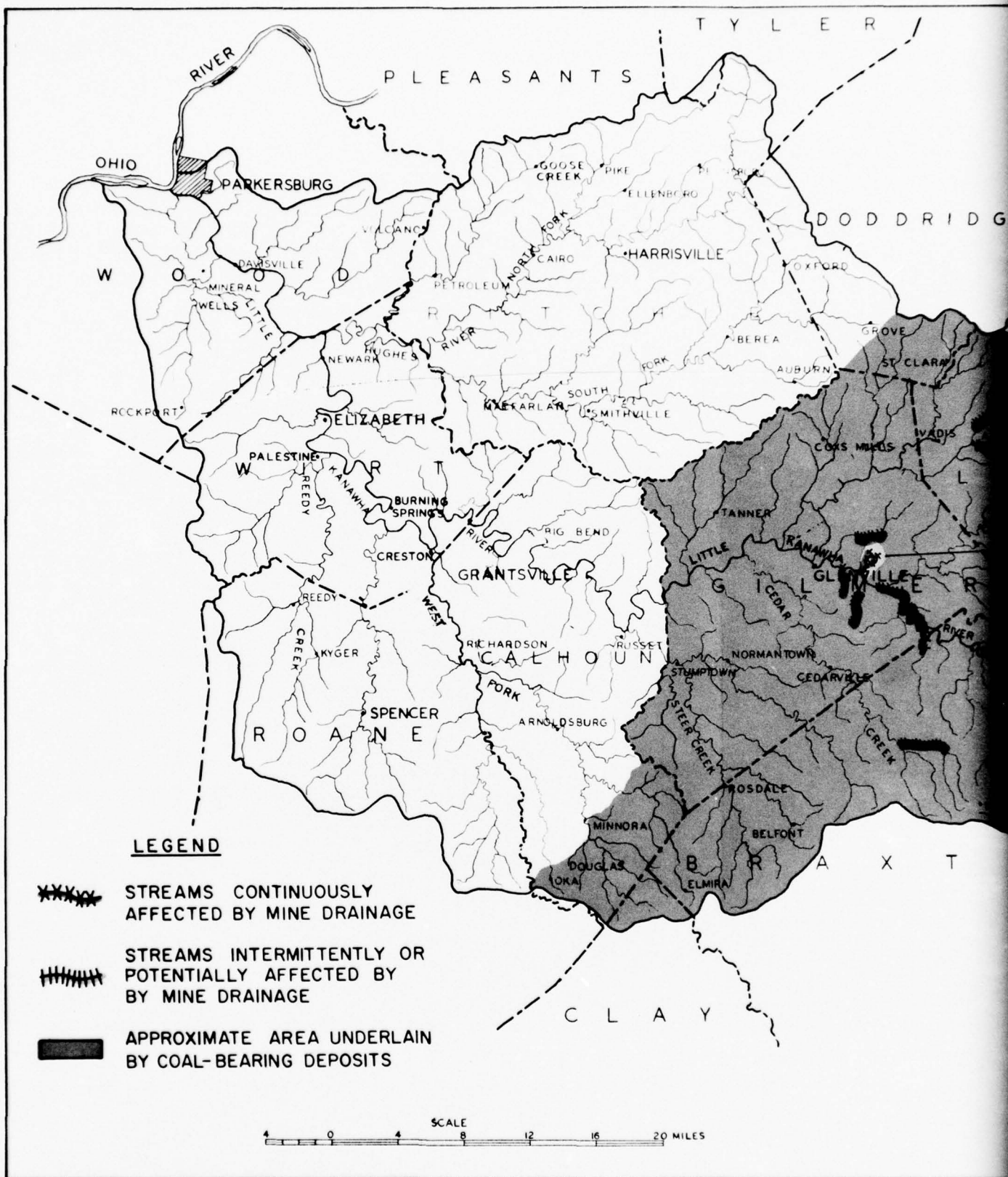
Mine Drainage Sources and Their
Effect on Stream Quality

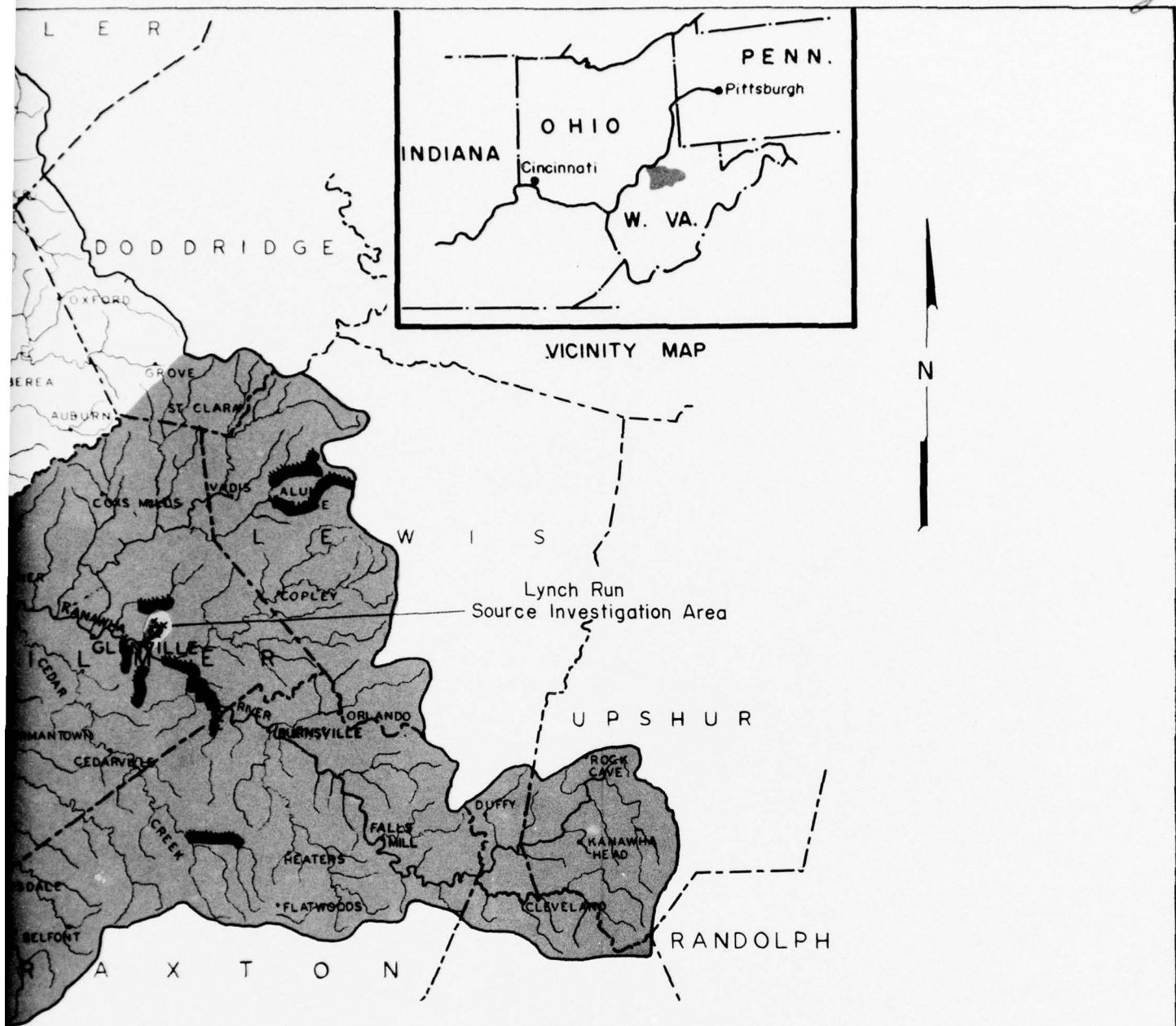
During detailed study of an area in the Lynch Run watershed (Fig. 47) 19 mine drainage sources were examined and 17 drainages were sampled and measured. The total number of sources is not known. A total of 4,000 acres of unreclaimed surface-mined land presently exists in the basin. It is estimated that 10 tons/day of acidity enters streams in the basin.

Water quality analyses of stream waters shows mine drainage to be present in the Little Kanawha River in its upper portions (Fig. 47). The Little Kanawha River is intermittently polluted by

mine drainage downstream to about Glenville in Gilmer County. The principal mine drainage contributors to the main stem are minor tributaries that enter the river between the Gilmer-Braxton county line and Glenville, West Virginia. Mine drainage pollution also occurs on an intermittent basis in portions of the headwaters areas of Leading and Cedar Creeks, tributaries to the Little Kanawha in Gilmer County.

About five miles of the Little Kanawha River is considered to be intermittently polluted by mine drainage. A total of 25 miles of tributary streams are considered to be polluted by mine drainage, 20 miles on an intermittent basis.





APPALACHIA MINE DRAINAGE POLLUTION
REPORT

Figure 47

LITTLE KANAWHA RIVER BASIN

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

Kanawha River Basin

Description

The Kanawha River basin spans the entire width of south-central West Virginia, includes the west-central portion of Virginia, and the northwestern part of North Carolina. It is bounded on the north by the Little Kanawha and Monongahela River basins, on the east by the Potomac and Roanoke River basins, on the south by the Pee Dee River basin, and on the west by the Tennessee, Big Sandy and Guyandotte River basins. The total drainage area of the Kanawha basin is 12,300 square miles, 8,450 of which are in West Virginia, 3,080 in Virginia, and 770 in North Carolina. The basin is entirely within the Appalachian Region (Fig. 48).

The Kanawha River is formed by the confluence of the New and Gauley Rivers at Gauley Bridge, West Virginia. From the point of origin it flows northwesterly for 95 miles to its junction with the Ohio River at Point Pleasant, West Virginia, 266 river miles below Pittsburgh. The main tributaries comprising the Kanawha River system are the Elk, Gauley, New and Greenbrier Rivers.

The entire Kanawha basin is mountainous in character, although the upper and lower portions comprise two contrasting types of topography. Rounded hills and wide valleys characterize the lower basin, and high mountains and deep gorges characterize the upper basin. Elevations range from a high of about 5,000 feet in the Blue Ridge Mountains of North Carolina to 538 feet at the mouth of the Kanawha River, giving a maximum relief of about 4,500 feet.

Bituminous coal deposits underlie 19 of the 21 West Virginia counties that are wholly or partly contained in the Kanawha River basin. Coal production has been reported for all but one of these 19 counties.

The recoverable coal reserve in the Kanawha basin, underlying about 70 percent of the total area of the watershed, amounts to an estimated 23 billion tons. There are no coal deposits in the Virginia and North Carolina portions of the basin.

The Kanawha basin coal fields were developed very early, and have been very large producers in the history of the coal mining industry in West Virginia. Three of the counties produced more than 500 million tons of coal in the period 1883-1965. Coal production in the Kanawha basin in 1965 amounted to over 46 million tons. The principal producing counties were Boone, Fayette, Kanawha, and Raleigh. (West Virginia Department of Labor and Industry, 1965).

Mine Drainage Sources and Their Effect on Stream Quality

During detailed investigation of the Heizer Creek and Cabin Creek watersheds (Fig. 48) 71 mine drainage sites were examined and 22 drainages were sampled. The total number of mine drainage sources in the Kanawha basin is not known. There are 64,000 acres of unreclaimed surface-mined land in the basin. It is estimated that 350 tons/day of unneutralized acidity reaches streams in the basin.

Some stream pollution from mine drainage in the basin occurs in nearly all coal mining areas, but it is particularly prevalent in Kanawha, Boone, and Nicholas Counties (Fig. 48). The Coal and Gauley River systems that traverse these counties contain 333 and 385 miles of mine drainage polluted streams, respectively (Table 15).

Significant mine drainage pollution occurs in the New, Gauley, Elk, Coal, and Pocatalico Rivers. Generally, serious pollution exists in the headwater areas of these drainages and in small tributaries to these streams. Pollution in the main streams is intermittent and water quality is not severely degraded. Significant intermittent pollution also occurs in Cabin Creek and Paint Creek, tributaries to the Kanawha River in southern Kanawha County.

Table 15 - Lengths of Streams Polluted by Mine Drainage
Kanawha River Basin

	<u>Drainage Area</u> <u>(Square Miles)</u>	<u>Continuously</u> <u>Polluted(Miles)</u>	<u>Intermittently</u> <u>Polluted(Miles)</u>	<u>Total</u>
Kanawha River	12,240		95	95
Tributaries		85	90	175
Pocatalico River		20		20
Tributaries		31	6	37
Coal River		63		63
Tributaries		104	18	122
Little Coal River		52		52
Tributaries		96		96
Elk River		20	14	34
Tributaries		60	67	127
Gauley River		87		87
Tributaries		133	165	298
New River				
Tributaries		108	89	197
		859	+	544 = 1,403

In the New River basin, the Bluestone River (Sta. 26, Fig. 48), Piney (Sta. 16) and Coal Creeks, and a number of small tributaries to the New River are affected.

The Gauley River receives intermittent mine drainage at various locations along its length (Fig. 48). Although the Gauley River is not intensely polluted, this drainage area contains more miles of affected streams than the other tributary watersheds in the Kanawha River basin.

The Elk River, water supply source for Charleston, West Virginia intermittently receives mine drainage from the Birch River in northern Nicholas County, Buffalo Creek in Clay County, and Blue Creek in Kanawha County. Mine drainage also occurs in the Elk River from mining areas in the Webster Springs area, Webster County.

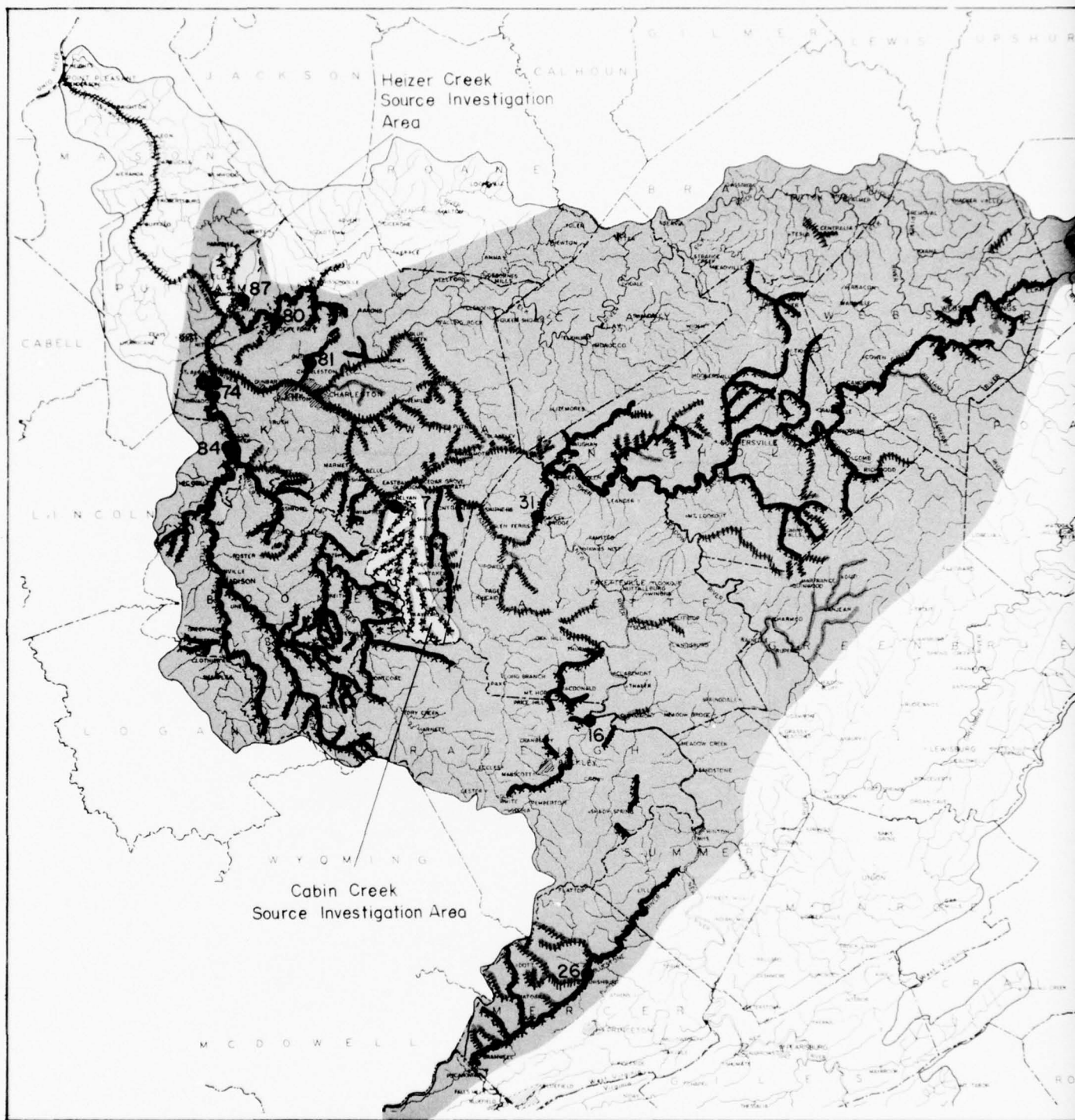
The Coal River (Sta. 74) and its principal tributary, Little Coal River (Sta. 84), receive mine drainage in their headwaters and many tributaries to these streams contribute mine drainage to the main stream. The Coal and Little Coal Rivers are intermittently polluted by mine drainage over their lengths. Sulfate concentrations of 250 mg/l are frequently exceeded in the Coal River watershed due to mine drainage.

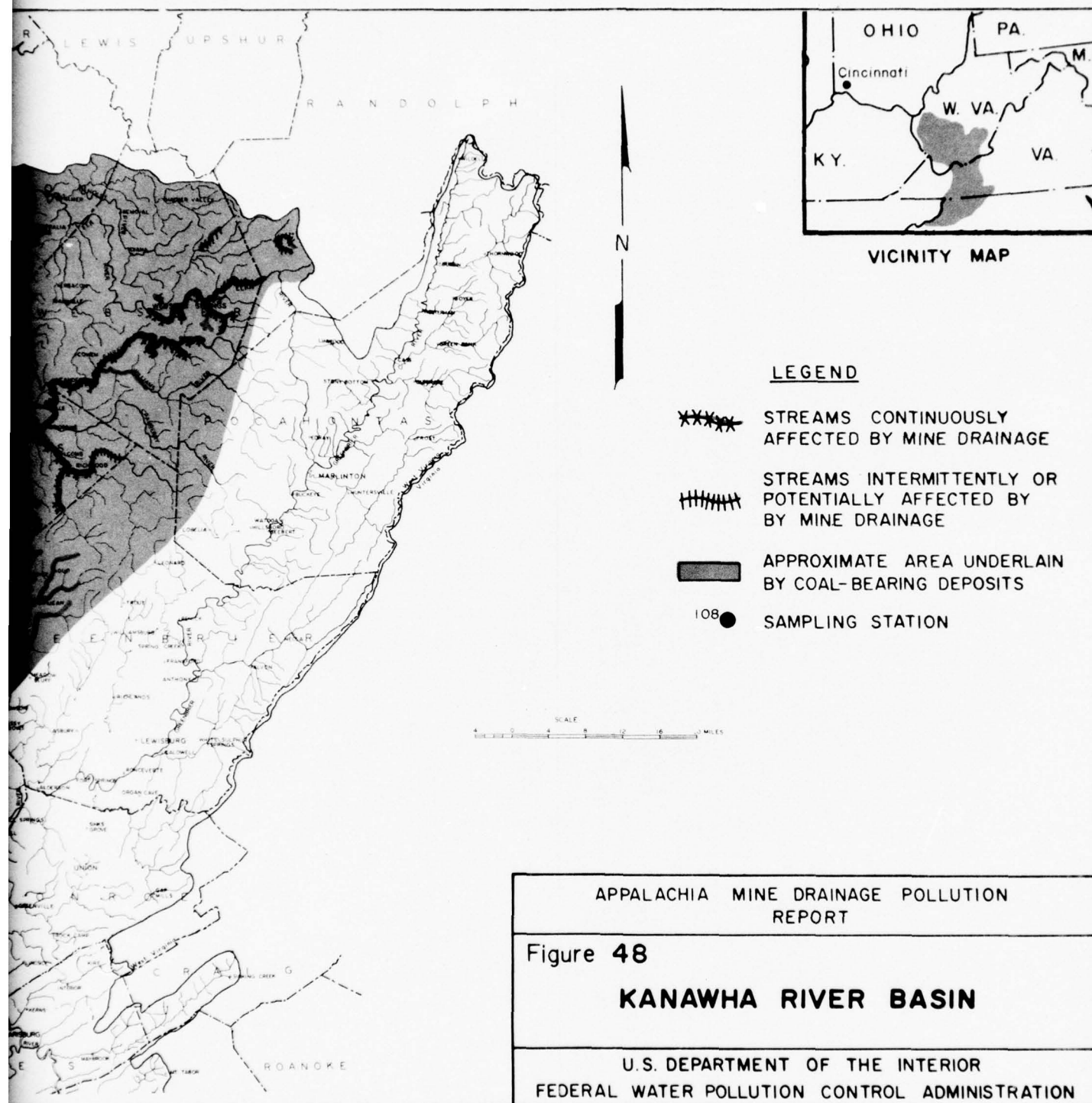
In the Pocatalico River drainage, a number of small tributaries are seriously polluted by mine drainage. A survey of water quality conditions in 1964 showed that over 25 tons of acid per day were being discharged into the Pocatalico River by these tributaries.

In many parts of the Kanawha basin coal mine discharges are alkaline rather than acid. A number of small communities utilize abandoned mines and mine discharges as sources of domestic supply.

Table 16 - Water Quality Data, Kanawha River basin

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Total Manganese (mg/l)	Total Aluminum (mg/l)	Flow (cfs)
26	16	7.9 9.6 Avg.	0.0 1.0 0.1	97.0 180.0 131.4	158.0 182.0 166.0		0.0 0.8 0.4			13.5 66.0 41.2
16	16	7.7 9.0 Avg.	0.0 2.0 0.4	37.0 80.0 59.5	56.0 152.0 117.8		0.2 0.6 0.4			5.3 29.5 13.8
31	16	6.7 9.8 Avg.	0.0 0.0 0.0	55.0 83.0 59.6	62.0 68.0 66.0		0.0 0.4 0.2			1100.0 4300.0 2762.5
7	16	4.9 6.6 Avg.	6.0 105.0 56.6	1.0 99.0 13.3	532.0 564.0 551.5		0.1 900.0 57.3			1.2 15.4 7.3
81	1	5.7	116.0	10.0			0.2			0.1
84	1	7.7	0.0	43.0			0.2			40.0
74	1	7.9	0.0	48.0	202.0		0.4			67.0
87	7	7.8 8.5 Avg.	0.0 0.0 0.0	75.0 99.0 86.0	136.0 248.0 176.6		0.5 1.2 0.9			0.5 1.5 0.8
80	1	3.8	950.0	0.0	1440.0	3590.0	75.0			0.4





Scioto River Basin

Description

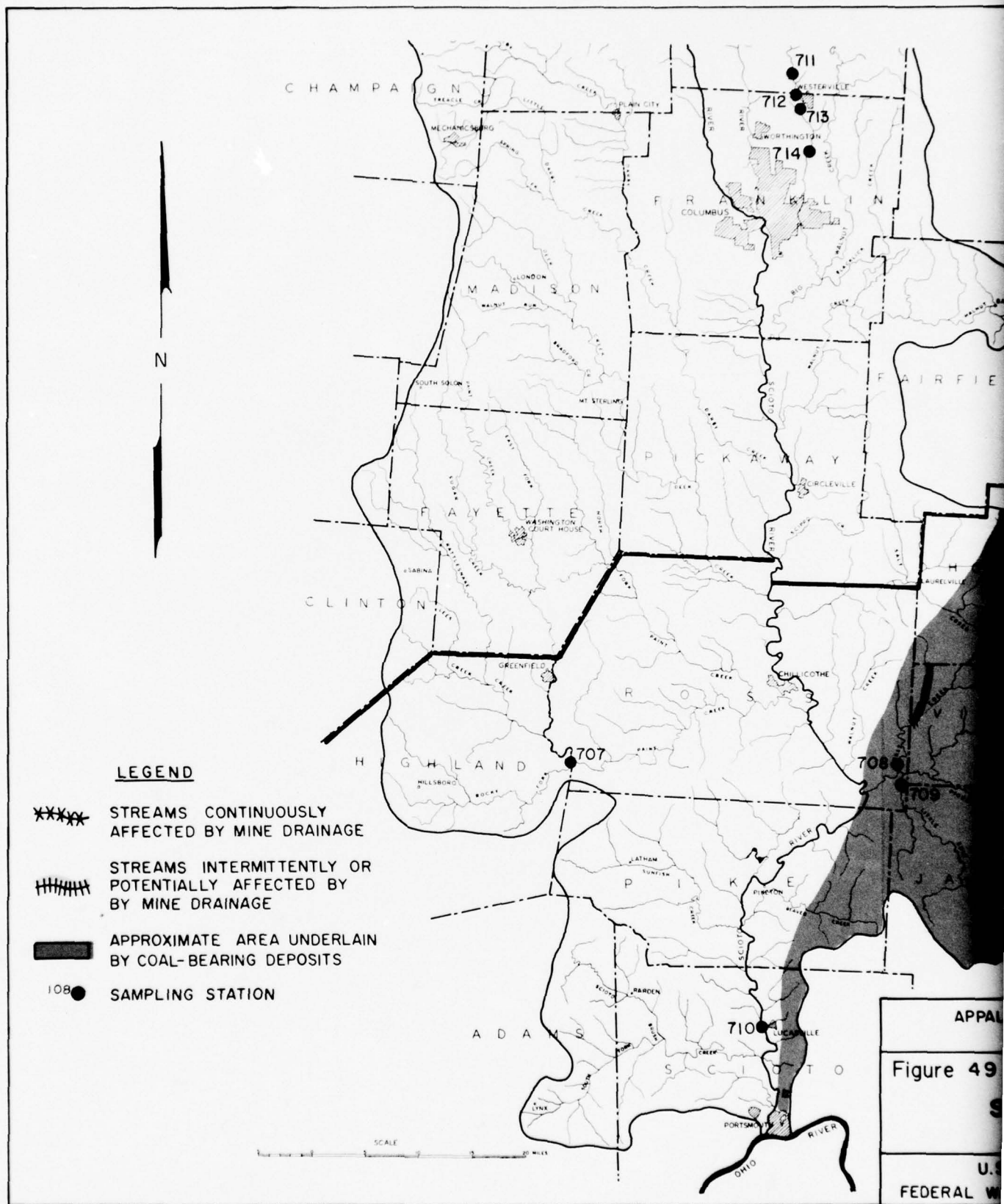
The Scioto River basin lies in central Ohio, its eastern limits nearly coinciding with the north-south center line of the State, and it forms the principal drainage system of central and southern Ohio. The total drainage area of the basin is 6,510 square miles, comprising about 16 percent of the land area of the State and covering part or all of 31 counties. The portions of eight counties that make up the lower Scioto basin, about one-third of the watershed, are contained in Appalachia.

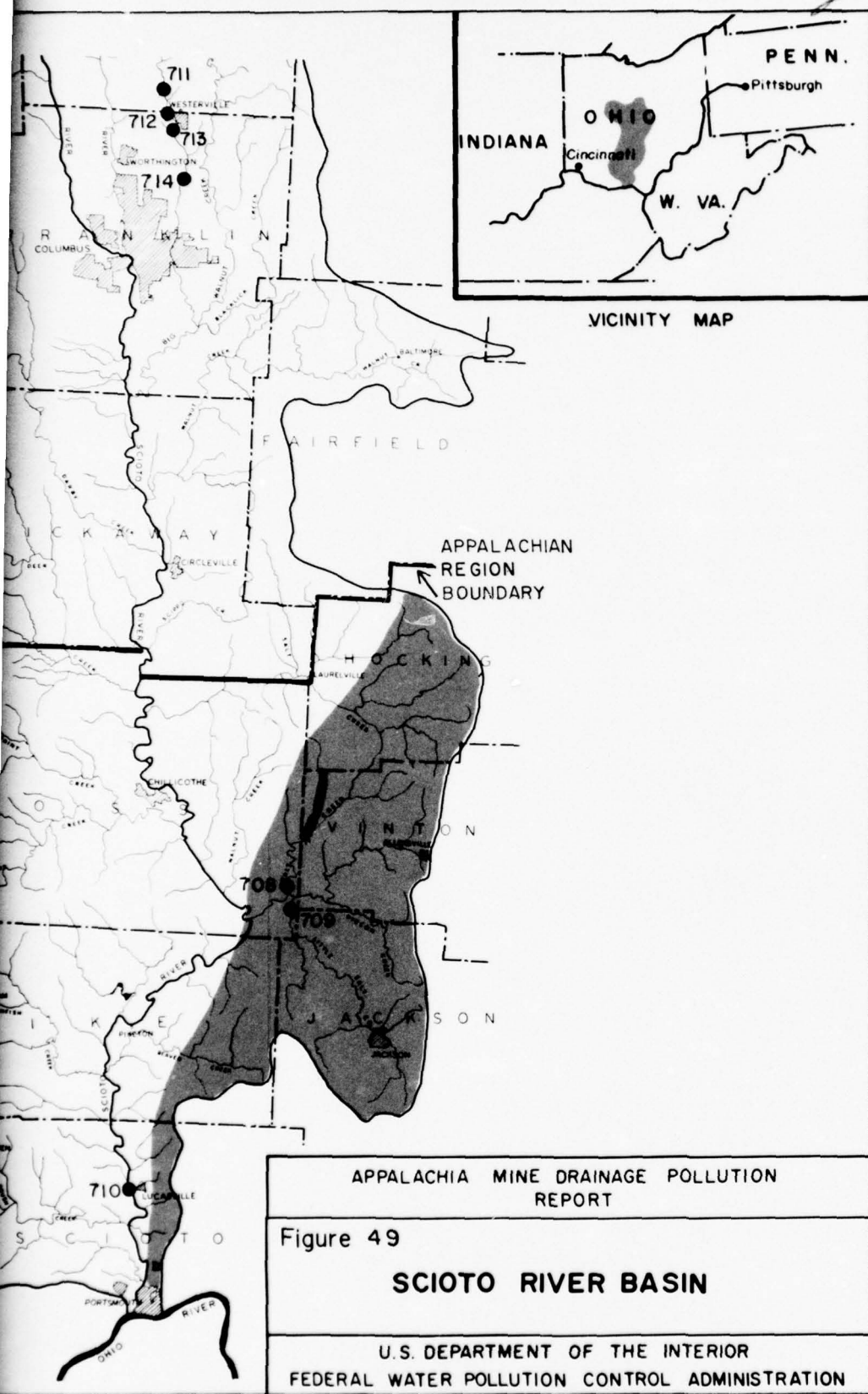
A small recoverable coal reserve of about 150 million tons is estimated for the Scioto basin. The Vinton and Jackson County portions of the watershed contain most of the reserve. Reported coal production is negligible and is limited to Jackson, Vinton, and Hocking Counties.

Mine Drainage Sources and Their Effect on Stream Quality

It is estimated that there are perhaps 200 significant pollution sources originating from inactive mines in the Scioto River basin. There are 1,000 acres of unreclaimed surface-mined land.

Significant stream pollution by coal mine drainage is limited to about 8 miles of streams in two small tributaries to Salt Creek in Vinton County (Fig. 49). About 5 tons/day of acidity is discharged to these streams.





Guyandotte River Basin

Description

The Guyandotte River drains 1,670 square miles of southwestern West Virginia, about seven percent of the state (Fig. 50). It is bounded on the west by the Big Sandy River basin and on the east by the Kanawha River basin. Eight counties lie wholly or partly in the basin. All of the Guyandotte River basin is contained in the Appalachian Region. The Guyandotte River has its source near Rhodell, West Virginia, in southern Raleigh County at the confluence of Winding Gulf and Stone Coal Creeks. It flows in a westerly direction for approximately 50 miles, then north for 115 miles to Huntington, where it discharges into the Ohio River, 305 miles below Pittsburgh, Pennsylvania. The only major tributary is the Mud River. Many small upper basin tributaries drain the important coal mining areas in Logan and Wyoming Counties and part of Raleigh County.

The topography of the basin is mountainous and consists of a maze of hills and valleys. Elevations range from under 1,000 feet to between 2,000 and 3,000 feet in the middle and upper portions of the basin. The gradient of the upper half of the river is 11 feet per mile, but in the lower 71 miles the gradient is only 1.8 feet per mile.

Recoverable coal reserves underlie almost all of the drainage area. Only portions of Mingo and Cabell Counties are devoid of mineable coal reserves. The recoverable coal reserve of the Guyandotte River basin is estimated at about five billion tons. The production of coal has been the dominant industry in this area for a long time and should continue to be in view of the remaining coal reserve.

Over the period of record, 1883-1965, over two billion tons of coal were produced from the basin. More than 30 million tons were produced in the basin in 1965. The principal producing counties were Logan, Wyoming, Lincoln and Raleigh (West Virginia Department of Mines, 1965). Logan County has the largest cumulative production figure, 885 million tons. Cabell County has no recorded coal production.

Mine Drainage Sources and Their
Effect on Stream Quality

About 200 tons/day of mine drainage acidity are estimated to be formed in the Guyandotte basin, about half of which enters streams unneutralized. A portion of this drainage originates in the 11,000 acres of unreclaimed surface-mined land in the basin.

Coal mining is the major industry in the upper half of the Guyandotte basin and a large number of streams there are affected by this activity (Fig. 50). Serious water quality problems are commonly caused by silt and fine coal particles emanating from coal mining and preparation sites. The Raleigh and Wyoming County portions of the basin are particularly affected in terms of numbers of streams and total miles of streams degraded.

A total of 288 miles of streams in the Guyandotte basin are considered to be continuously polluted, including the total length of the Guyandotte River (164 miles) and 124 miles of tributary streams. Eleven miles of tributary streams are intermittently polluted.

The Guyandotte receives mine drainage in its upper portion from Stone Coal Creek, Devils Fork, Allen Creek, Slab Fork, and Barkers Creek (Sta. 178). The Guyandotte River at Tralee, West Virginia (Sta. 190), below the affected tributaries mentioned, contained acidity in excess of alkalinity on one occasion during the stream survey. The stream pH did not fall under 6.8 but total mineralization, hardness, sulfate, iron, and manganese were high as a result of the upstream mine drainage influence.

Downstream from Tralee the Guyandotte River receives small amounts of mine drainage from tributaries in Wyoming County above Clear Fork, principally Pinnacle and Indian Creeks.

The Clear Fork was the largest contributor of acidity to the Guyandotte River during the 1966 survey. Virtually the entire Clear Fork watershed is polluted. Laurel Fork of Clear Fork near Jesse, West Virginia (Sta. 179) carried a net acidity load of 12 tons/day and had a minimum pH of 5.4. Clear Fork at Toney Fork, West Virginia (Sta. 180) had a pH range of 3.5 to 5.7 and carried a net acidity load of 37 tons/day.

Little Huff Creek, which enters the main stream at the Wyoming County line (Sta. 184) discharged an average acid load of 5 tons/day during the study period.

Little additional mine drainage enters the Guyandotte in the Logan County reach of the stream. Island Creek is the principal affected stream in this section. Island Creek was an alkaline stream when studied but had high concentrations of hardness, sulfate, iron, and manganese (Sta. 187).

The Guyandotte River near Logan, West Virginia (Sta. 198) was an alkaline stream and had assimilated the acid loads received over the Wyoming County reach of the drainage area. Residual effects of mine drainage were reflected at this location in high concentrations of other related constituents.

The Guyandotte River at Branchland, West Virginia (Sta. 189) is generally an alkaline stream, but as at Logan it had high hardness, sulfate, and metal concentrations. Near its mouth, the Guyandotte was alkaline, but carried high concentrations of mine drainage-related constituents (Sta. 197).

One of the major water quality problems in the Guyandotte basin is the intermittent occurrence of fine coal and silt in the streams. These materials are washed from mining areas during periods of precipitation, or, are allowed to escape from mining and preparation facilities.

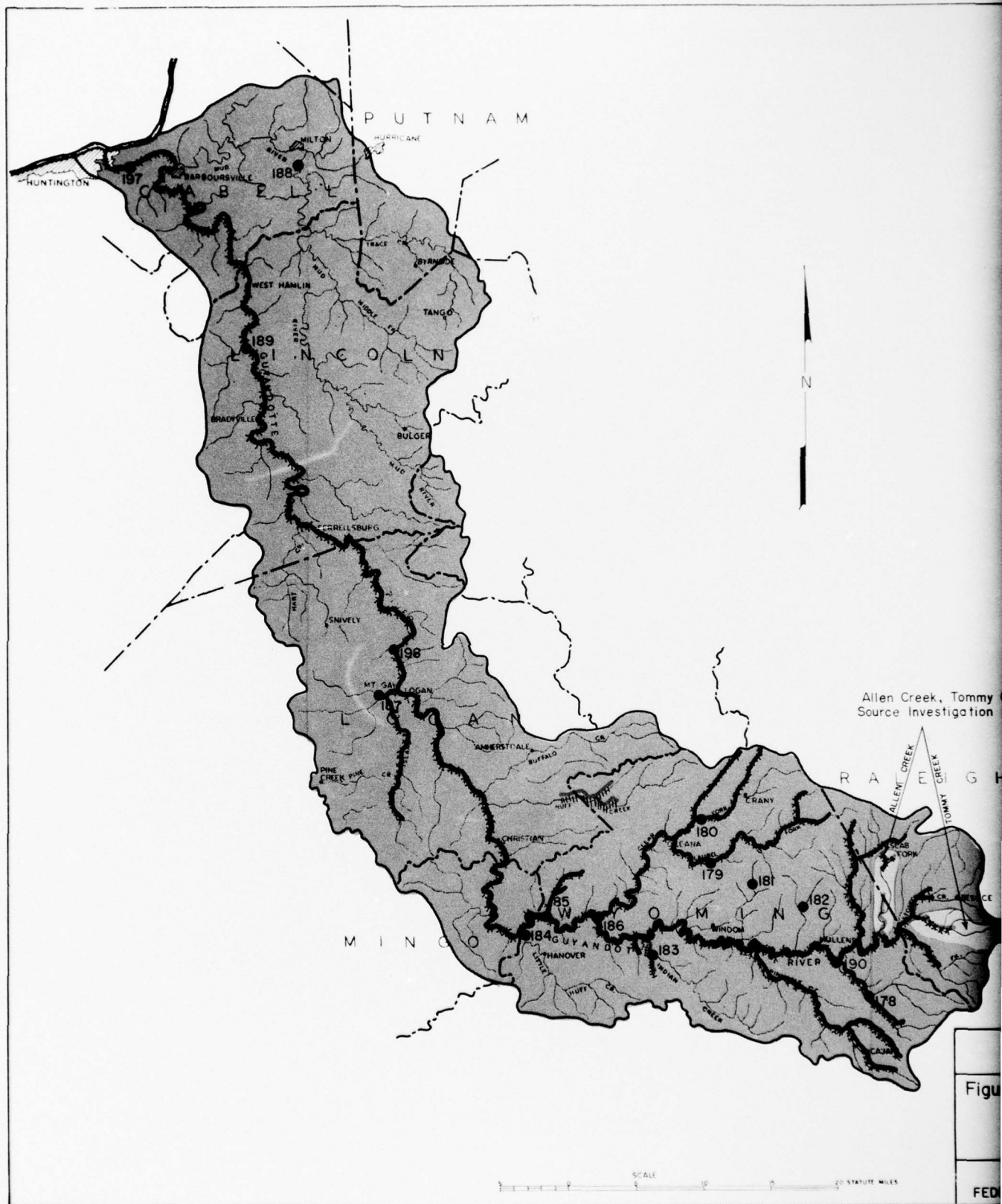
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Table 17 - Water Quality Data, Guyandotte River basin

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Total Manganese (mg/l)	Total Aluminum (mg/l)	Flow (cfs)
178	6	6.7 7.7 Avg.	0.0 61.0 17.0	12.0 119.0 34.0	23.0 110.0 55.5	35.0 66.0 46.5	0.0 8.4 1.8	0.0 2.1 0.6	0.8 8.5 2.5	0.4 76.5 18.0
179	6	5.4 7.1 Avg.	5.0 115.0 38.0	2.0 54.0 26.7	45.0 109.0 73.8	40.0 130.0 81.2	0.6 12.0 3.2	0.5 2.4 0.9	1.1 5.0 2.6	2.0 500.0 145.2
180	6	3.5 5.7 Avg.	58.0 608.0 274.8	0.0 13.0 3.8	162.0 340.0 251.2(5)*	165.0 690.0 348.3	0.0 216.0 42.4	2.0 58.6 13.7	7.5 260.0 59.7	0.5 180.0 63.9
181	6	3.8 6.5 Avg.	5.0 25.0 16.3	0.0 17.0 9.8	14.0 70.0 32.5	20.0 23.0 20.3	0.2 0.5 0.4	0.0 0.3 0.2	0.3 0.6 0.5	0.4 12.0 3.2
182	4	6.1 7.3 Avg.	3.0 24.0 12.5	10.0 18.0 13.3	15.0 58.0 33.3	14.0 23.0 19.3	0.6 4.2 1.9	0.2 0.8 0.4	0.7 5.9 2.8	1.0 28.9 10.9
183	6	6.7 7.2 Avg.	0.0 115.0 31.2	8.0 74.0 40.8	24.0 57.0 40.5	3.0 25.0 15.3	0.5 1.2 0.8	0.1 0.4 0.2	0.6 4.2 2.0	0.4 220.0 61.3
184	6	6.4 7.1 Avg.	12.0 79.0 40.3	8.0 150.0 41.2	15.0 115.0 60.7	30.0 75.0 55.7	0.6 18.7 5.1	0.2 3.1 0.9	0.0 18.7 5.1	1.0 420.0 94.4
185	6	6.8 7.6 Avg.	0.0 39.0 15.7	18.0 196.0 86.0	74.0 162.0 101.2	75.0 238.0 121.3	0.0 6.2 2.5	0.2 3.4 1.0	0.0 4.0 1.5	65.0 4120.0 966.2

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Total Manganese (mg/l)	Total Aluminum (mg/l)	Flow (cfs)
186	6	5.1 5.5 Avg.	7.0 316.0 82.0	1.0 15.0 5.0	26.0 297.0 148.2	65.0 425.0 216.7	0.0 94.0 17.5	0.7 14.0 4.4	1.0 13.0 6.1	1.0 430.0 131.0
187	6	6.7 7.6 Avg.	0.0 28.0 12.2	20.0 334.0 250.3	135.0 300.0 214.2	225.0 625.0 445.8	3.1 8.8 5.6	0.3 0.7 0.5	0.0 8.1 3.3	20.0 80.0 35.4
188	6	6.4 8.0 Avg.	0.0 20.0 9.3	7.0 48.0 36.8	35.0 82.0 56.5	2.0 30.0 17.5	0.1 5.9 1.3(5)	0.0 3.4 1.2	0.1 2.1 1.1(5)	1.0 975.0 163.0
189	6	6.7 7.3 Avg.	0.0 27.0 7.0	22.0 121.0 76.5	95.0 248.0 166.5	90.0 400.0 212.5	0.3 8.4 2.4	0.0 0.7 0.4	1.9 6.2 3.1	83.0 2855.0 661.0
190	6	6.8 7.9 Avg.	0.0 28.0 9.5	26.0 199.0 136.5	73.0 170.0 125.2	53.0 260.0 179.7	1.1 3.4 1.9	0.1 1.6 0.7	1.1 3.6 2.3	26.5 900.0 200.3
197	6	6.6 7.5 Avg.	0.0 28.0 8.7	38.0 100.0 67.7	100.0 198.0 141.0	110.0 340.0 195.8	0.2 4.9 2.5	0.1 1.1 0.5	0.4 4.7 3.2	110.0 6000.0 1346.7
198	6	6.9 7.4 Avg.	0.0 26.0 9.8	22.0 155.0 86.0	70.0 230.0 168.3	85.0 345.0 210.8	0.4 3.8 1.7	0.1 0.8 0.4	0.9 8.2 4.2	65.0 250.0 105.0

*(5) Indicates the number of samples used in averages when other than the maximum.





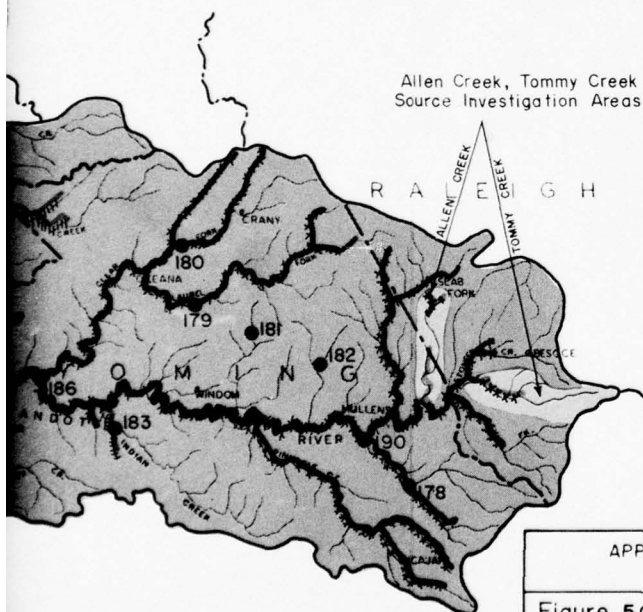
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LEGEND

- *** STREAMS CONTINUOUSLY AFFECTED BY MINE DRAINAGE
- ||||| STREAMS INTERMITTENTLY OR POTENTIALLY AFFECTED BY MINE DRAINAGE
- APPROXIMATE AREA UNDERLAIN BY COAL-BEARING DEPOSITS
- SAMPLING STATION

Allen Creek, Tommy Creek
Source Investigation Areas



APPALACHIA MINE DRAINAGE POLLUTION
REPORT

Figure 50

GUYANDOTTE RIVER BASIN

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

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Big Sandy River Basin

Description

The Big Sandy River is formed by the junction of Tug and Levisa Forks at Louisa, Kentucky, and flows northerly 27 miles to enter the Ohio River about 10 miles downstream from Huntington, West Virginia. It drains 4,280 square miles, of which 2,330 are drained by Levisa Fork and 1,550 by Tug Fork (Fig. 51). Principal tributaries to Levisa Fork of the Big Sandy River are Russell Fork, Beaver Creek, and Johns Creek. The basin is bounded by the Guyandotte River basin on the east, the Tennessee River basin on the south and the Kentucky and Licking River basins on the west. All of the Big Sandy River basin is within the Appalachian Region.

The basin varies from mountainous terrain in its upper portions to hilly areas along the Big Sandy River. Some of the most rugged portions of the three states is found in the headwaters of the Tug and Levisa Forks of the Big Sandy River.

Coal production is the major industry in the basin and there are more than 2,800 active mines, the majority of which are underground. Bituminous coal reserves are present in 16 of the counties that are either wholly or partly within the basin. In 1963 the total recoverable coal reserves were estimated to be more than 11 billion tons. Coal has been mined in most of the counties, and in 1965 production was more than 65 million tons. The major producing counties were Pike and Floyd Counties in Kentucky; Buchanan, Dickinson, and Wise Counties in Virginia; and McDowell and Mingo Counties in West Virginia.

Mine Drainage Sources and Their Effect on Stream Quality

Sulfate loadings in the Big Sandy at Cattletsburg (Ceredo) for the years 1957-1959 and 1962-1963 averaged 800 tons/day (Fig. 52), of which 620 tons/day is considered to have originated from mine drainage acidity. About 300 tons/day of unneutralized acidity is estimated to reach streams in the basin.

Approximately 500 miles of streams in the Big Sandy basin are polluted by coal mine drainage and activities related to coal mining as shown in Table 18. Part of the pollutants in these streams originate in the 31,000 acres of unreclaimed strip-mined land in the basin. It is not known how many individual pollution sources may exist. Thirty potential pollution sites were examined in the Dismal Fork area (Fig. 51), but only two of the thirty had drainage.

Table 18 - Lengths of Streams Polluted by Mine Drainage
Big Sandy River Basin

Stream	Drainage Area (square miles)	Continuously Polluted (miles)	Intermittently Polluted (miles)	Total (miles)
Big Sandy River	4,294		27	27
Tributaries to Big Sandy			2	2
Tug Fork			70	70
Tributaries		58	74	132
Levisa Fork			131	131
Tributaries			138	138
		<hr/> 58	+ <hr/> 442	= <hr/> 500

Tributary streams of the basin in which mine drainage pollution effects have been observed to be the most serious are those in the headwaters in McDowell and Mingo Counties, West Virginia, Buchanan and Dickinson Counties, Virginia; and Pike and Floyd Counties, Kentucky. The streams in these locations drain the areas of heaviest mining activity in the basin.

Generally, the streams in the Big Sandy River basin that are affected by mine drainage, although highly mineralized, are not characterized by high acidity concentrations. Fine coal and silt are often present in the streams of the basin due to surface runoff and discharges from coal mining and preparation sites. Concern has been expressed over detrimental effects of coal washery discharges above Fishtrap Reservoir on Levisa Fork near the Kentucky-Virginia line.

Tug Fork of Big Sandy River receives some intermittent mine drainage directly in its reach above Welch, West Virginia and from the Elkhorn Creek, Dry Fork, and Panther Creek watersheds (Sta. 192) in McDowell County, West Virginia. Tug Fork near Taeger, West Virginia (Sta. 194) reflected the mine drainage influence in total mineralization, and high sulfate, iron, and manganese concentrations.

In the Mingo County, West Virginia reach of the Tug Fork several small tributaries contribute mine drainage to the main stream above Williamson, West Virginia. Below Williamson, Pigeon Creek in West Virginia and Big and Wolf Creeks in Kentucky are affected. Pigeon Creek (Sta. 196) had a minimum pH of 6.4 during the survey. It contained high hardness, sulfate, iron, and manganese concentrations on occasion and had acidity in excess of alkalinity on one occasion.

Tug Fork below Pigeon Creek, near Kermit, West Virginia (Sta. 195) had a minimum pH of 5.9, acidity in excess of alkalinity on one occasion,

and high concentrations of sulfate, iron, and manganese during part of the study period.

Like Tug Fork, Levisa Fork is affected in its headwaters area. The pH in the Levisa Fork at the Kentucky-Virginia State line (Sta. 02) did not fall below 6.7 but the river contained high concentrations of mine drainage-related constituents. Russell Fork (Sta. 03) contributed an average net acid load of 20 tons/day. The pH of this stream did not fall below 6.2. Levisa Fork below Pikeville (Sta. 09) contained high residual concentrations of sulfate, iron, and manganese from mine drainage received in its upper reaches.

Below Pikeville there are a number of tributaries to Levisa Fork that intermittently contribute additional quantities of mine drainage in Floyd and Johnson Counties, Kentucky. Beaver, Middle, Johns, Toms, and Greasy Creeks in these counties are intermittently polluted by mine drainage.

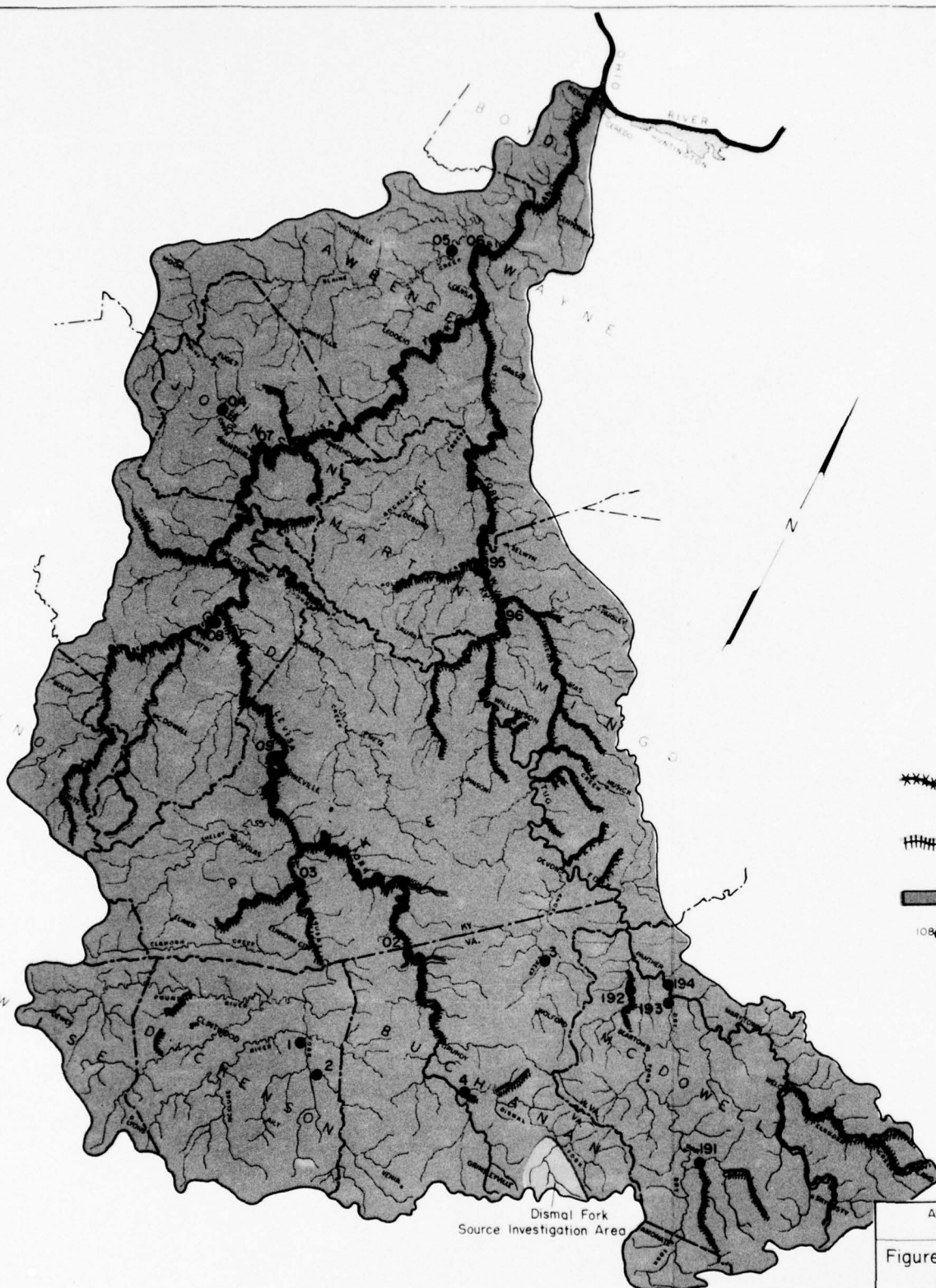
The Big Sandy River at Louisa, Kentucky (Sta. 06) contained acidity in excess of alkalinity during part of the survey period and had a hardness range of 60 to 582 mg/l. Sulfate, iron, and manganese concentrations were 52 to 320 mg/l, 1.0 to 25.0 mg/l, and 0.1 to 1.3 mg/l, respectively.

Table 19 - Water quality data, Big Sandy River basin

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Total Manganese (mg/l)	Total Aluminum (mg/l)	Flow (cfs)
02	Min.	6.7	0.0	13.0	103.0	80.0	0.6	0.3	1.4	6.7
	Max.	7.8	28.0	56.0	348.0	400.0	9.1	1.6	9.9	4300.0
	Avg.		14.0	32.8	251.7	233.3	3.1	0.8	4.0	759.3
03	Min.	6.2	0.0	20.0	18.0	40.0	0.5	0.7	1.3	27.3
	Max.	7.9	175.0	55.0	124.0	100.0	115.0	12.4	107.0	3470.0
	Avg.		39.7	36.2	69.0	70.0	22.3	3.1	21.1	1533.1
04	Min.	6.7	0.0	35.0	144.0	15.0	0.0	0.2	0.0	2.0
	Max.	7.8	96.0	66.0	656.0	50.0	16.8	1.3	63.8	61.0
	Avg.		21.0	48.7	336.2	29.2	3.3	0.5	11.2	25.7
05	Min.	6.4	13.0	15.0	190.0	12.0	0.0	0.1	0.6	11.0
	Max.	7.0	63.0	38.0	920.0	30.0	12.0	2.5	25.2	320.0
	Avg.		30.7	24.5	455.0	23.2	3.1	1.1	7.3	92.6
06	Min.	6.9	2.0	19.0	60.0	52.0	1.0	0.1	1.2	170.0
	Max.	7.4	92.0	86.0	582.0	320.0	25.0	1.3	19.1	1680.0
	Avg.		28.3	49.3	190.3	139.5	7.0	0.7	6.1	889.2
07	Min.	6.2	0.0	25.0	58.0	45.0	0.0	0.3	0.0	105.0
	Max.	7.4	43.0	48.0	140.0	110.0	15.6	4.6	24.0	11000.0
	Avg.		18.8	33.2	93.0	79.5	6.0	1.4	7.8	3980.5
08	Min.	7.2	0.0	28.0	54.0	85.0	1.0	0.3	0.4	8.1
	Max.	7.6	24.0	111.0	186.0	185.0	5.0	1.5	3.4	690.0
	Avg.		13.8	74.0	142.2	135.8	2.8	0.8	1.9	225.6
09	Min.	6.7	0.0	29.0	60.0	40.0	1.2	0.5	2.1	190.0
	Max.	7.7	35.0	65.0	152.0	155.0	10.3	2.9	9.8	6900.0
	Avg.		20.5	41.3	105.0	96.3	6.3	1.6	6.4	2341.7

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Total Manganese (mg/l)	Total Aluminum (mg/l)	Flow (cfs)
1	6	6.9 7.8 Avg.	0.0 25.0 10.3	46.0 125.0 80.7	50.0 130.0 80.7	36.0 195.0 86.7	0.4 3.4 1.2	0.0 2.4 0.8	0.3 2.5 1.2	0.5 228.0 57.4
2	6	7.4 8.4 Avg.	0.0 25.0 6.5	56.0 167.0 93.5	25.0 128.0 77.5	40.0 245.0 105.2	0.1 1.6 0.6	0.0 1.3 0.4	0.4 3.0 1.4	0.4 98.2 29.8
3	6	5.8 7.2 Avg.	0.0 48.0 18.7	10.0 87.0 46.3	15.0 255.0 146.0	35.0 270.0 139.8	0.5 16.8 3.6	0.2 2.9 0.8	0.7 22.5 4.8	0.3 1400.0 265.2
4	6	5.5 7.9 Avg.	5.0 59.0 26.8	2.0 27.0 17.5	107.0 350.0 249.8	80.0 415.0 240.8	0.4 9.1 2.8	0.7 1.8 1.3	0.0 9.4 3.2	1.7 360.0 73.7
191	6	6.6 7.2 Avg.	5.0 50.0 25.7	9.0 60.0 33.0	37.0 273.0 139.2	40.0 300.0 138.8	0.3 21.6 4.5	0.2 3.3 1.2	0.1 17.2 4.3	0.2 1100.0 193.7
192	6	6.6 7.3 Avg.	4.0 46.0 25.7	12.0 46.0 29.0	13.0 67.0 46.2	25.0 86.0 51.5	0.3 6.0 2.3	0.2 1.1 0.6	0.4 4.0 1.8	1.0 1630.0 292.8
193	6	6.4 8.6 Avg.	0.0 31.0 8.0	47.0 326.0 194.2	38.0 110.0 87.7	45.0 130.0 80.8	0.0 13.4 3.2	0.1 2.9 0.7	0.0 17.5 4.8	18.6 880.0 230.1
194	6	6.8 8.1 Avg.	0.0 57.0 20.2	52.0 299.0 193.3	67.0 188.0 118.8	50.0 220.0 133.2	0.0 14.3 3.9	0.1 2.8 0.8	0.0 14.9 6.0	63.0 2879.0 784.3

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Total Manganese (mg/l)	Total Aluminum (mg/l)	Flow (cfs)
195	5	Min.	5.9	18.0	46.0	55.0	0.0	0.2	1.4	116.0
		Max.	8.2	148.0	202.0	255.0	5.1	1.0	4.0	5232.0
		Avg.	22.8	71.0	115.6	111.0	2.4	0.6	2.8	2150.2
196	6	Min.	6.4	12.0	70.0	60.0	0.0	0.0	0.0	6.0
		Max.	7.2	74.0	348.0	610.0	2.8	1.2	2.8	1400.0
		Avg.	10.0	30.8	151.7	187.8	1.6	0.4	1.7	398.3



LEGEND

- STREAMS CONTINUOUSLY AFFECTED BY MINE DRAINAGE
- STREAMS INTERMITTENTLY OR POTENTIALLY AFFECTED BY MINE DRAINAGE
- APPROXIMATE AREA UNDERLAIN BY COAL-BEARING DEPOSITS
- 108 ● SAMPLING STATION

APPALACHIA MINE DRAINAGE POLLUTION REPORT

Figure 51

BIG SANDY RIVER BASIN

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

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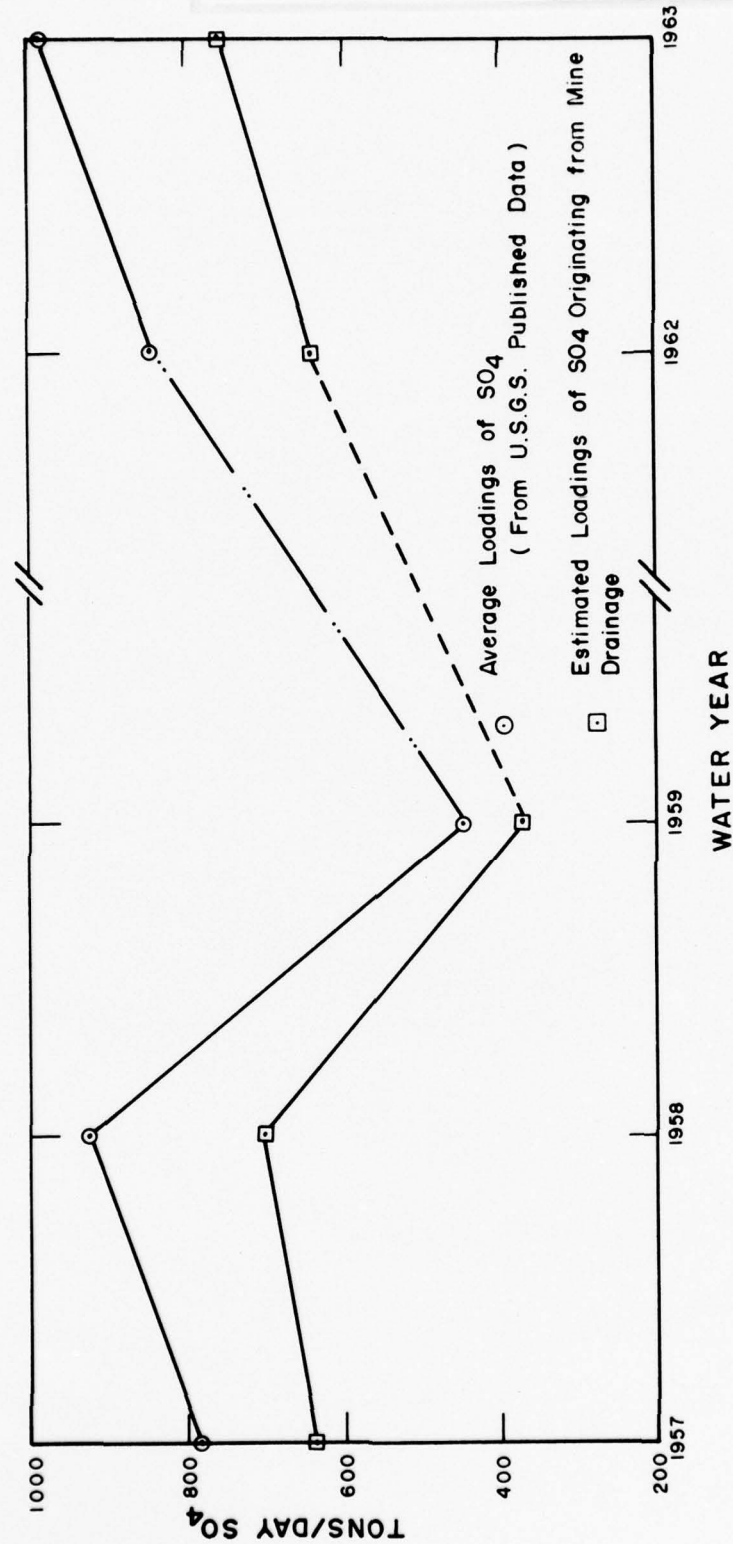


Figure 52. Average loads of total sulfate and sulfate considered to originate from coal mine drainage carried by the Big Sandy River at Catlettsburg, Kentucky.

Ohio River Main Stem and Minor Tributaries

Description

Areas along both banks of the Ohio River main stem from Pittsburgh, Pennsylvania to Meldahl Dam on the Ohio near Foster, Kentucky, draining directly to the river, are included in this section of the study. The sum of the minor tributary drainage areas along this 438 mile stretch of the Ohio River is about 14,000 square miles. The largest of the tributaries in this area so defined are Little Beaver Creek (Ohio-Pennsylvania); Middle Island Creek (West Virginia); Raccoon Creek (Ohio); Twelvepole Creek (West Virginia); Little Muskingum River (Ohio); and Ohio Brush Creek (Ohio). With the exception of Columbiana and Mahoning Counties (Ohio) in the Pittsburgh to New Cumberland Dam reach of the Ohio River, and Bracken and Mason Counties, Kentucky, in the Belleville to Meldahl Dam reach, the entire drainage area is contained in the Appalachian Region.

The valley of the Ohio River gradually widens downstream. At Point Pleasant, West Virginia, the valley contains alluvial deposits about two and one-half miles wide and in some places these deposits are over 100 feet thick. The Ohio Valley is bordered by an almost continuous band of rough unglaciated land from the mountainous headwater regions of western Pennsylvania through the hilly country of southeastern Ohio into the Knobs section of Kentucky. The minor tributary drainage areas are generally hilly and rough.

Approximately 30 million tons of coal were produced in this watershed in 1965. More than one-half of the tonnage was from the State of Ohio, and the total tonnage was about equally divided between surface and underground mining methods. Production in this area will greatly increase in the near future to supply fuel requirements of a number of steam electric generating plants which are proposed to be built along the Ohio River.

Mine Drainage Sources and Their Effect on Stream Quality

Source investigations have been made in four of the minor tributary watersheds along the upper Ohio River as listed below and as shown in Figures 53, 54 and 55. Additional data concerning source type and acid contribution are given in Table 1-A. Inactive surface and underground mines are the principal source of drainage in the Wheeling and Raccoon Creek drainages. Two active surface mines contribute most of the drainage to Captina Creek.

Mine Drainage Source Areas Studied
Ohio Main Stem

<u>Watershed</u>	<u>Area (square miles)</u>	<u>Drainages Sampled and Measured</u>
Yellow Creek (Figure 53)	44	4
Wheeling Creek (Figure 55)	49	72
Captina Creek (Figure 55)	180	12
Raccoon Creek (Figure 55)	57	142

A total of 48,000 acres of unreclaimed strip-mined land presently exist in this area. Surface and underground sources are estimated to contribute 1000 tons/day of unneutralized acidity to the upper Ohio River and its minor tributaries.

Over 1,300 miles of minor tributaries to the Ohio River were found to be significantly affected by mine drainage (Table 20). About 90 percent of the affected streams were found to be continuously polluted.

Table 20. Length of Streams Polluted by Mine Drainage
Upper Ohio River Main Stem and Minor Tributaries

<u>Stream</u>	<u>Drainage Area (square miles)</u>	<u>Continuously Polluted (miles)</u>	<u>Intermittently Polluted (miles)</u>	<u>Total (miles)</u>
Pittsburgh to New Cumberland Minor Tributaries	1,609		24	24
		159		159
New Cumberland to Belleville Dam Minor Tributaries	3933			
		365	38	403
Belleville Dam to Meldahl Dam Minor Tributaries	7,090			
		640	104	744
		<u>1,164</u>	<u>166</u>	<u>1,330</u>

A. Pittsburgh to New Cumberland Dam

The Ohio River in this upper drainage area is affected by mine drainage primarily due to the influence of the Monongahela River. The Ohio River at the Ohio-West Virginia-Pennsylvania state boundary

carried an average acidity load of about 350 tons/day over the period 1945 to 1960. The Ohio River is presently considered to be intermittently polluted by mine drainage from its origin to the entry of the Beaver River 25 miles downstream.

In the drainage area of this reach of the Ohio River there are 195 miles of streams polluted by mine drainage. Polluted minor tributaries include Chartiers Creek, Montour Run, Raccoon Creek, Sixmile Run, and Yellow Creek (Fig. 53). Chartiers Creek and its tributary, Robinson Run, and Raccoon Creek are the most seriously affected.

Chartiers Creek was not an acid stream during the 1966 survey, but did contain high hardness, sulfate, iron, and manganese from mine drainage discharged within its drainage area (Sta. 587). The pH of Raccoon Creek ranged from 3.3 to 5.1 during the survey (Sta. 588) and the stream discharged an average load of 25 tons/day acidity to the Ohio. Yellow Creek is affected by mine drainage over most of its length, but is not acid. The pollution is reflected by high levels of mine drainage indicators (Sta. 681).

B. New Cumberland Dam to Belleville Dam

The middle reach of the Ohio drains an area of 3,933 square miles of Ohio, Pennsylvania, and West Virginia. Mine drainage stream pollution in this area is more severe than in the upper drainage area. Some 400 miles of streams are polluted in varying degrees by mine drainage in this watershed (Fig. 54 and Table 20).

Listed in downstream order, tributary basins significantly polluted with mine drainage are: Harmon Creek (West Virginia); Cross, Short, Wheeling, McMahon, Captina, Sunfish and Duck Creeks (Ohio). All these streams exhibit high concentrations of one or more of the constituents prevalent in mine drainage (i.e., hardness, sulfate, iron, and manganese).

During 1966 Harmon Creek (Sta. 174) and McMahon Creek (Sta. 685) were consistently acid and discharged average net acidity loads of 32 tons and 1 ton/day, respectively, to the Ohio River. The other streams sampled generally contained alkalinity in excess of acidity but discharged large iron, manganese, hardness and sulfate loads to the Ohio River.

Tributary watersheds carrying mine drainage in smaller amounts include Aunt Clara, Cross, Buffalo, Short, and Wheeling Creeks in West Virginia and Little Muskingum River in Ohio. Additional drainage enters the Ohio River from active and inactive mine sites located along this reach of the Ohio River valley.

Two fish kills, resulting from acid mine drainage, are reported to have occurred in minor tributaries in this portion of the Ohio River basin during 1966.

C. Ohio River Belleville Dam to Meldahl Dam

The lowermost minor tributary watershed area is more severely polluted than either of the upper tributary watersheds. This section contains more than 700 miles of streams polluted by mine drainage (Fig. 55 and Table 20). The Raccoon Creek basin, which drains 684 square miles of southeastern Ohio contains 230 miles of polluted streams and is the most severely affected tributary watershed in this reach. Nearly all of the affected streams in this area are in Ohio.

Proceeding downstream the tributary basins significantly polluted with mine drainage are: Shade River, Leading Creek, Raccoon Creek, Symmes Creek, and Pine Creek, Ohio. Other affected watersheds include Campaign Creek, Indian Guyan Creek and Little Scioto River in Ohio and Twelvepole Creek in West Virginia.

Shade River (Sta. 687) and Leading Creek (Sta. 688) in Meigs County, Ohio, were sampled during the survey. These streams exhibited minimum pH readings of 4.0 and 6.7 and each discharged an average acid load of 2.5 tons/day. Both streams were acidic through most of the survey.

Raccoon Creek enters the Ohio River near Gallipolis, Ohio, draining some of the oldest and most intensively mined areas of southeastern Ohio. Mining in this watershed began on a large scale in 1856 coincident with railroad construction. Stream surveys by the Ohio River Basin Project of the FWPCA in 1965 and 1966 show that most of the streams in the Raccoon Creek basin are grossly polluted by mine drainage and are acid in character. Acidity concentrations as high as 424 mg/l and pH readings as low as 2.8 were recorded during these studies. Raccoon Creek carried an average net acidity load of 100 tons/day, seven miles below the mouth of Little Raccoon Creek.

Table 21 - Water quality data, main stem Ohio River basin

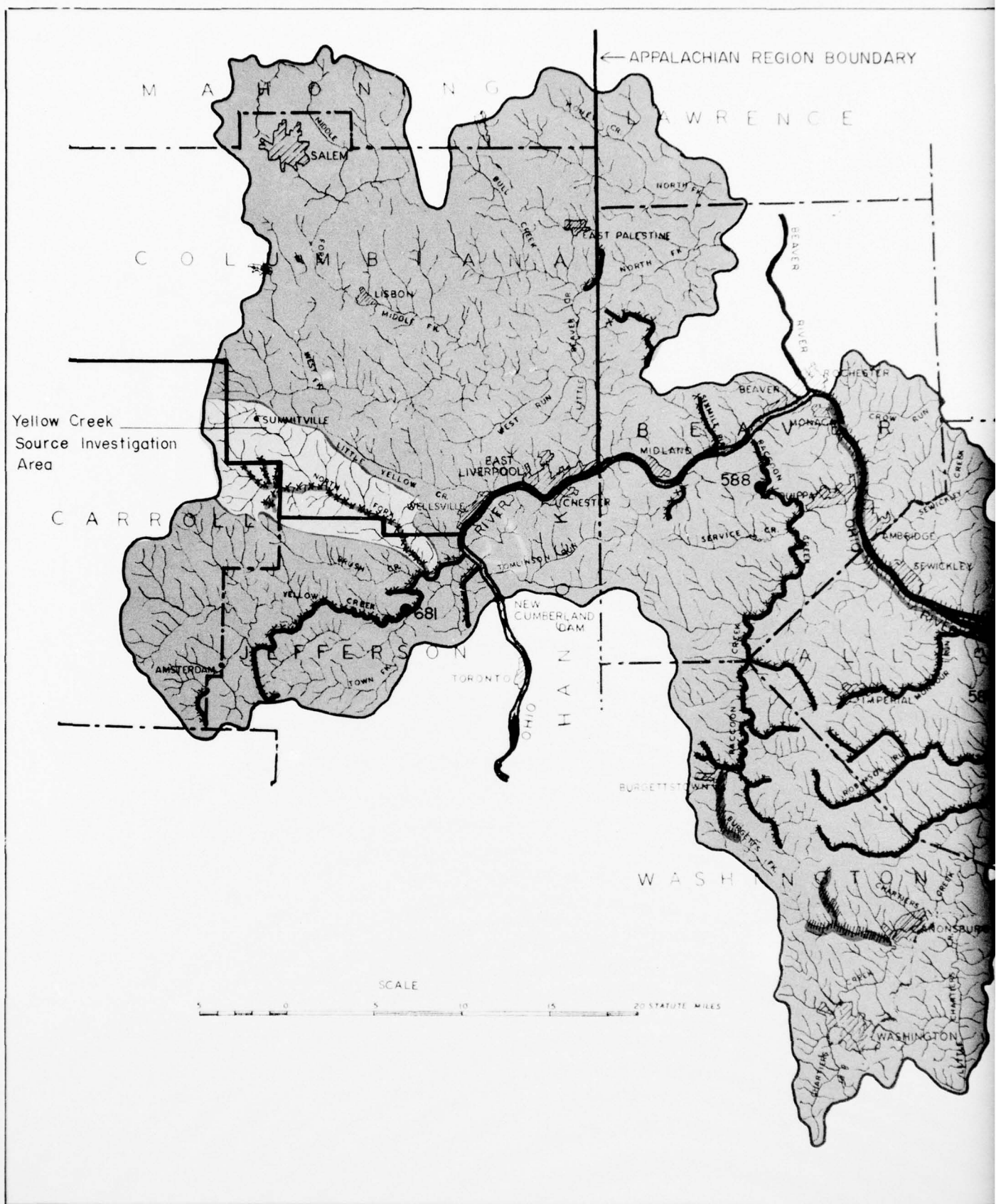
Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Total Manganese (mg/l)	Total Aluminum (mg/l)	Flow (cfs)
10	6	6.9 7.7 Avg.	0.0 20.0 6.2	91.0 119.0 100.8	80.0 140.0 116.7	28.0 45.0 35.7	0.0 2.7 0.9	0.0 1.5 0.5	0.0 3.4 1.2	2.9 300.0 99.3
11	6	6.8 7.4 Avg.	0.0 18.0 6.8	21.0 42.0 28.7	35.0 76.0 45.2	10.0 32.0 21.3	0.0 3.2 0.8	0.0 0.2 0.1	0.0 1.1 0.4	1.7 77.4 17.8
174	7	3.8 6.7 Avg.	20.0 125.0 70.4	0.0 15.0 5.4	205.0 294.0 246.4	85.0 375.0 233.6	1.3 71.0 32.7	1.5 2.8 2.3	0.0 20.7 6.3	160.0 186.0 175.1
175	6	6.7 7.4 Avg.	0.0 27.0 12.3	26.0 53.0 37.2	747.0 1016.0 937.2	150.0 750.0 480.0	0.2 4.8 2.2	1.8 4.1 3.0	0.8 19.0 7.6	0.5 10.0 4.7
176	6	6.6 7.6 Avg.	0.0 25.0 7.0	69.0 138.0 119.0	136.0 1061.0 415.8	85.0 425.0 206.0	1.4 14.2 4.1	0.3 5.9 2.2	1.0 18.3 4.8	6.0 64.0 18.9
199	4	5.3 7.4 Avg.	0.0 5.0 1.3	50.0 88.0 61.3	60.0 94.0 71.8	5.0 20.0 13.8	0.5 1.1 0.7	0.2 1.1 0.6	0.0 1.9 0.8	0.0 0.4 0.1
200	6	6.7 7.5 Avg.	0.0 5.0 0.8	52.0 63.0 56.8	65.0 104.0 86.2	14.0 20.0 17.8	0.2 0.5 0.3	0.0 0.3 0.2	0.0 1.5 0.6	0.1 7.0 3.9
201	6	6.7 7.4 Avg.	0.0 5.0 1.5	62.0 81.0 68.8	69.0 98.0 81.2	2.0 25.0 15.7	0.5 0.7 0.6	0.3 0.8 0.6	0.0 1.0 0.7	0.1 20.0 3.8

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Total Manganese (mg/l)	Total Aluminum (mg/l)	Flow (cfs)
202	6	7.0 7.2 Avg.	0.0 13.0 4.7	35.0 60.0 50.7	46.0 75.0 63.0	12.0 35.0 24.2	0.8 4.8 1.6	0.1 2.4 0.9	0.1 3.6 1.5	0.0 80.0 16.0
203	6	6.8 7.2 Avg.	0.0 18.0 9.2	15.0 51.0 33.2	22.0 60.0 44.7	7.0 27.0 17.7	0.8 2.7 1.9	0.2 0.7 0.4	0.9 2.6 1.6	1.0 90.0 20.7
587	6	6.3 7.1 Avg.	5.0 41.0 22.3	18.0 75.0 45.2	522.0 852.0 604.2	400.0 800.0 491.7	2.4 9.6 5.7	2.8 3.6 3.2	5.5 27.4 13.6	62.0 80.0 70.8
588	6	3.3 5.1 Avg.	131.0 362.0 244.8	0.0 0.0 0.0	345.0 816.0 627.3	305.0 800.0 463.3	0.1 7.2 3.4	1.1 14.7 8.3	0.0 69.4 27.4	14.0 57.0 34.2
681	6	6.1 7.4 Avg.	1.0 20.0 9.2(5)*	7.0 18.0 13.2(5)	262.0 285.0 270.2	185.0 350.0 250.0	0.0 2.4 0.5	0.0 1.0 0.6	0.2 7.7 2.0	9.0 25.0 14.8
682	6	6.7 7.5 Avg.	0.0 22.0 6.5	66.0 82.0 73.0	590.0 1005.0 820.3	300.0 850.0 510.8	0.0 2.4 0.7	0.3 2.4 1.0	0.0 8.1 2.0	9.0 24.7 15.1
683	6	6.6 7.5 Avg.	0.0 15.0 5.0	110.0 145.0 127.2	920.0 2560.0 1475.7	300.0 1750.0 698.3	1.1 16.8 6.7	0.0 3.3 1.2	4.0 16.2 10.0	24.0 131.0 89.7
684	6	7.3 8.0 Avg.	0.0 11.0 2.0	82.0 147.0 121.5	366.0 1363.0 1001.8	345.0 950.0 460.0	2.4 7.2 3.4	0.2 1.1 0.4	0.0 21.8 8.3	14.0 29.0 22.4

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Total Manganese (mg/l)	Total Aluminum (mg/l)	Flow (cfs)
685	6	4.6 6.6 Avg.	0.0 125.0 73.2	0.0 17.0 8.0	730.0 1031.0 877.8	15.0 450.0 296.7	0.6 9.6 4.6	1.0 2.0 1.5	0.0 24.6 11.0	3.8 9.0 7.1
686	6	5.3 6.8 Avg.	0.0 61.0 14.0	5.0 83.0 48.5	295.0 381.0 333.8	144.0 500.0 241.2	0.5 19.2 4.7	1.3 2.9 1.7	1.0 4.4 2.4	1.8 7.0 4.2
687	6	4.0 7.1 Avg.	9.0 178.0 56.7	0.0 45.0 24.3	144.0 193.0 168.7	76.0 750.0 236.8	0.0 3.8 1.4	0.6 7.3 3.4	0.4 9.2 3.6	0.1 60.0 19.2
688	6	6.7 7.0 Avg.	15.0 37.0 25.7	7.0 35.0 24.7	160.0 280.0 219.8	95.0 270.0 193.7	0.5 4.1 2.0	2.8 6.2 5.0	1.0 3.6 2.1	0.1 180.0 35.2
700	6	6.8 7.3 Avg.	0.0 28.0 12.3	17.0 68.0 45.8	50.0 156.0 121.8	62.0 85.0 73.5	1.2 8.7 3.0	0.6 2.8 1.7	1.5 10.5 4.0	8.0 320.0 98.9
701	6	6.2 7.1 Avg.	0.0 27.0 7.8	22.0 50.0 31.8	40.0 82.0 56.2	13.0 30.0 24.5	0.6 1.8 1.0	0.1 2.1 0.6	0.3 2.0 1.1	0.1 2.0 0.6
702	6	7.2 8.0 Avg.	0.0 27.0 7.7	91.0 210.0 163.2	146.0 205.0 163.8	22.0 40.0 33.8	0.2 6.4 1.4	0.1 3.3 0.8	0.1 9.3 2.4	1.3 2400.0 413.2
703	6	7.4 8.0 Avg.	14.0 103.0 39.5	103.0 201.0 169.0	101.0 230.0 161.2	28.0 40.0 35.5	0.0 2.9 0.7	0.2 0.7 0.3	0.0 6.7 1.9	0.1 17.0 7.3
704	4	7.5 8.1 Avg.	0.0 33.0 18.8	133.0 152.0 141.3	98.0 190.0 141.3	31.0 43.0 36.8	0.1 0.5 0.4	0.1 1.9 0.6	0.1 0.8 0.6	0.0 3.0 1.3

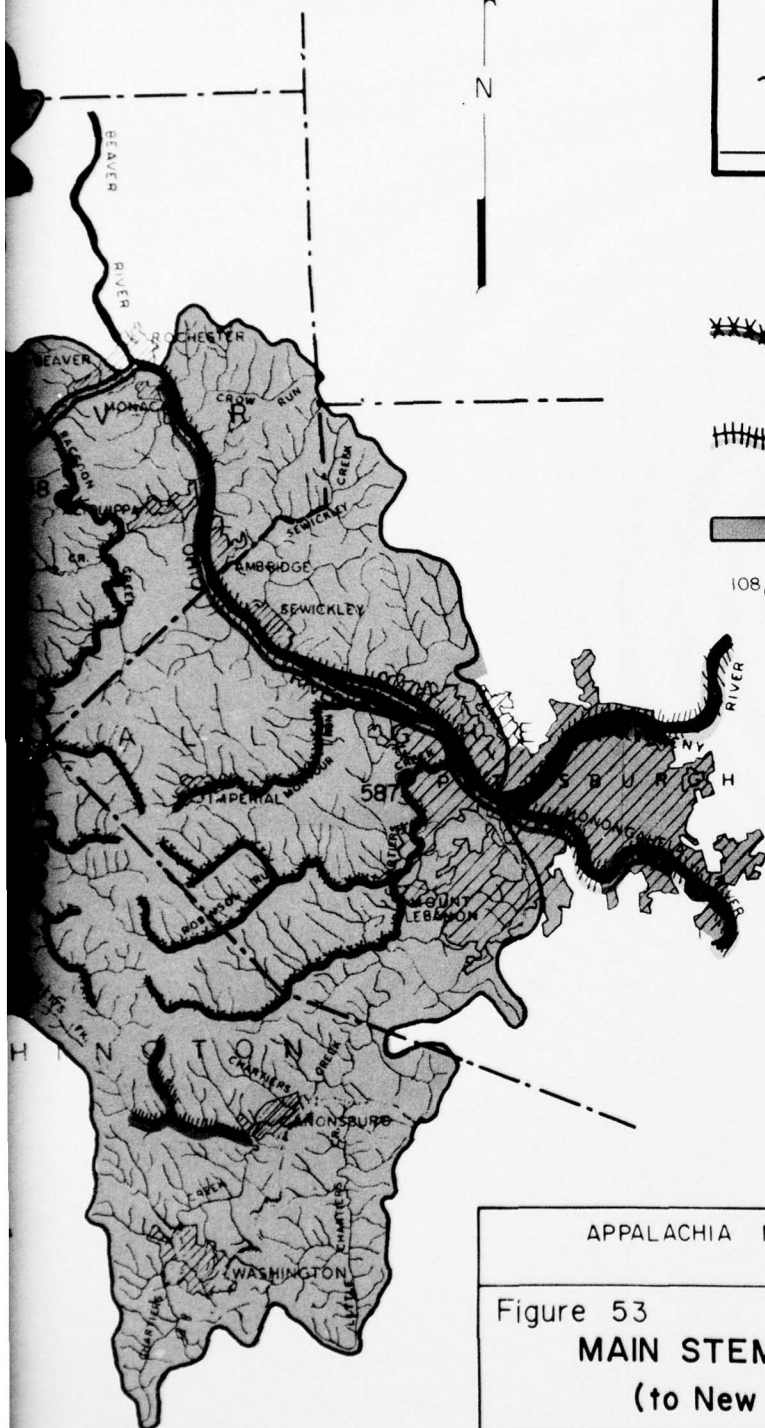
Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Total Manganese (mg/l)	Total Aluminum (mg/l)	Flow (cfs)
705	Min.	7.6	2.0	103.0	110.0	24.0	0.0	0.0	0.0	0.1
	Max.	8.6	42.0	165.0	200.0	55.0	1.0	2.8	2.5	6.0
	Avg.		18.7	130.5	160.0	43.7	0.4	0.7	1.1	3.4
706	Min.	7.4	4.0	90.0	91.0	22.0	0.1	0.0	0.5	0.1
	Max.	9.0	37.0	188.0	236.0	45.0	0.6	4.3	1.7	12.4
	Avg.		23.2	132.2	152.6	35.4	0.4	1.0	1.2	5.3
837	Min.	7.2	0.0	111.0	112.0	35.0	0.2	0.2	0.6	0.1
	Max.	7.3	9.0	111.0	156.0	35.0	0.4	0.3	0.9	0.1
	Avg.		4.5	111.0	134.0	35.0	0.3	0.3	0.8	0.1
838	Min.	7.6	0.0	20.0	140.0	105.0	0.5	0.7	0.8	13.3
	Max.	7.8	0.0	30.0	156.0	115.0	0.5	0.8	1.1	23.7
	Avg.		0.0	25.0	148.0	110.0	0.5	0.8	1.0	18.5
839	Min.	4.0	128.0	0.0	192.0	260.0	0.7	6.6	5.6	27.8
	Max.	4.2	130.0	0.0	260.0	265.0	1.0	8.8	12.0	51.0
	Avg.		129.0	0.0	226.0	262.5	0.9	7.7	8.8	39.4

*(5) Indicates the number of samples used in averages when other than the maximum.



AN REGION BOUNDARY

R E N C E



VICINITY MAP

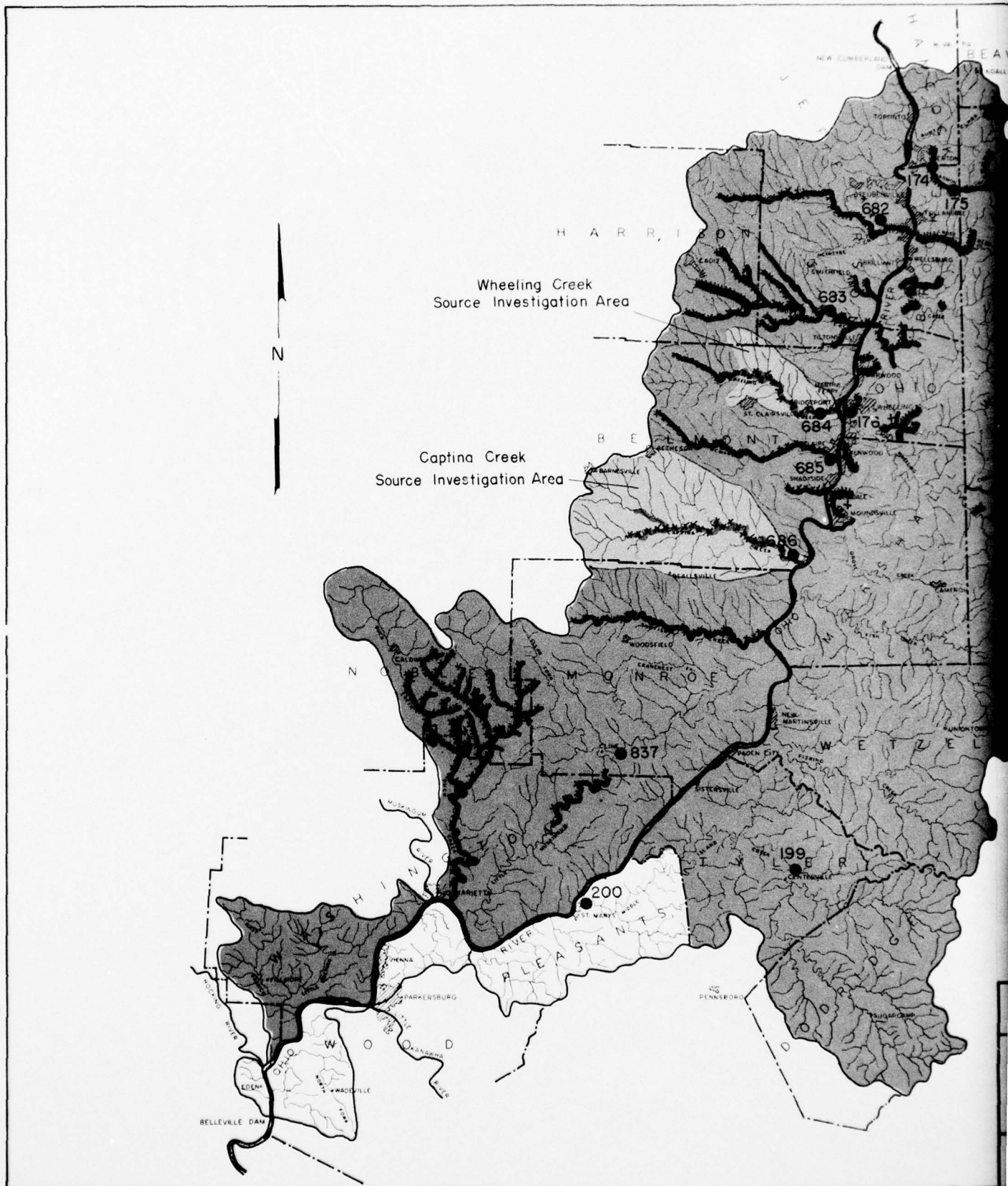
LEGEND

- STREAMS CONTINUOUSLY AFFECTED BY MINE DRAINAGE
- STREAMS INTERMITTENTLY OR POTENTIALLY AFFECTED BY MINE DRAINAGE
- APPROXIMATE AREA UNDERLAIN BY COAL-BEARING DEPOSITS
- SAMPLING STATION

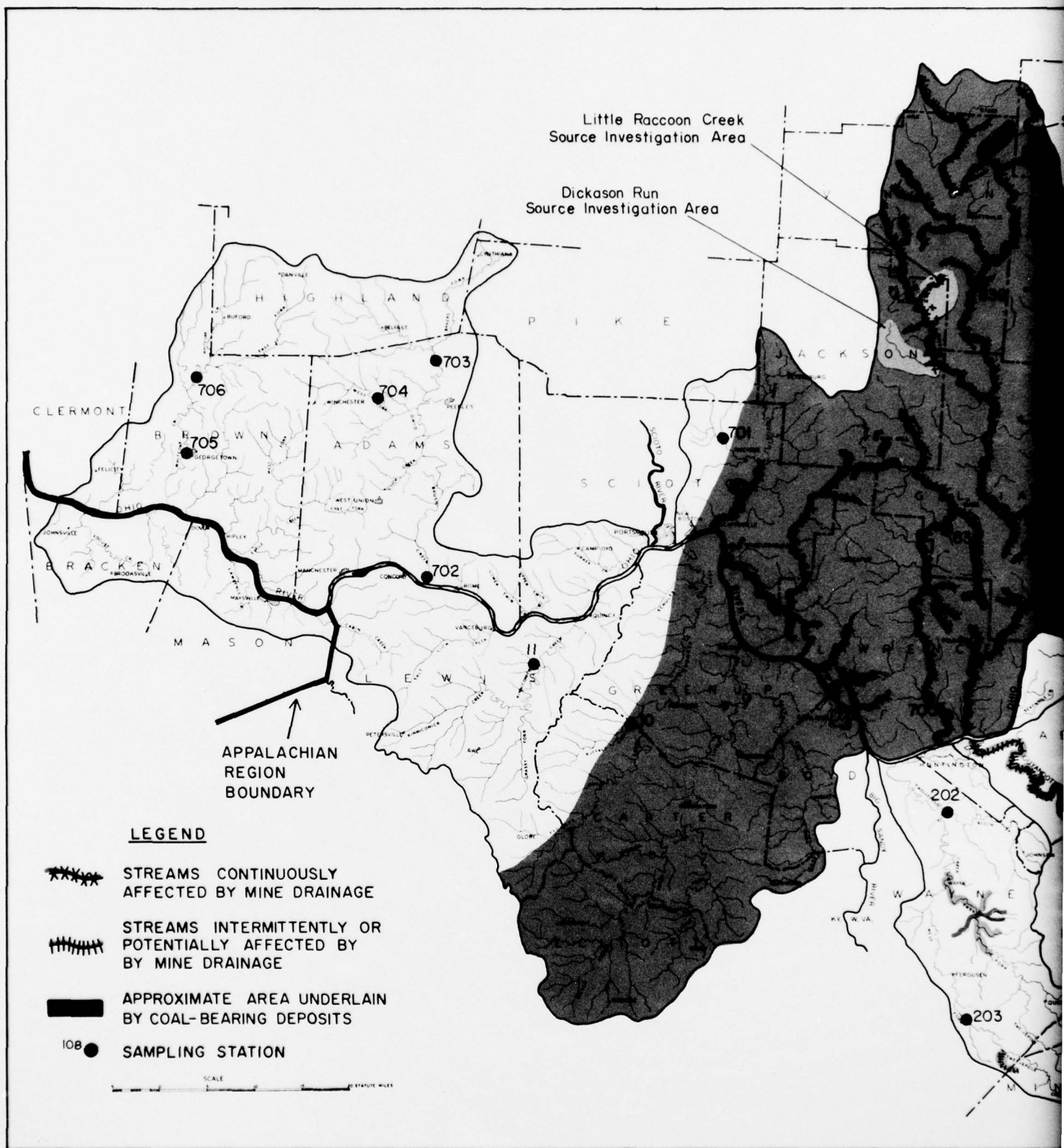
APPALACHIA MINE DRAINAGE POLLUTION
REPORT

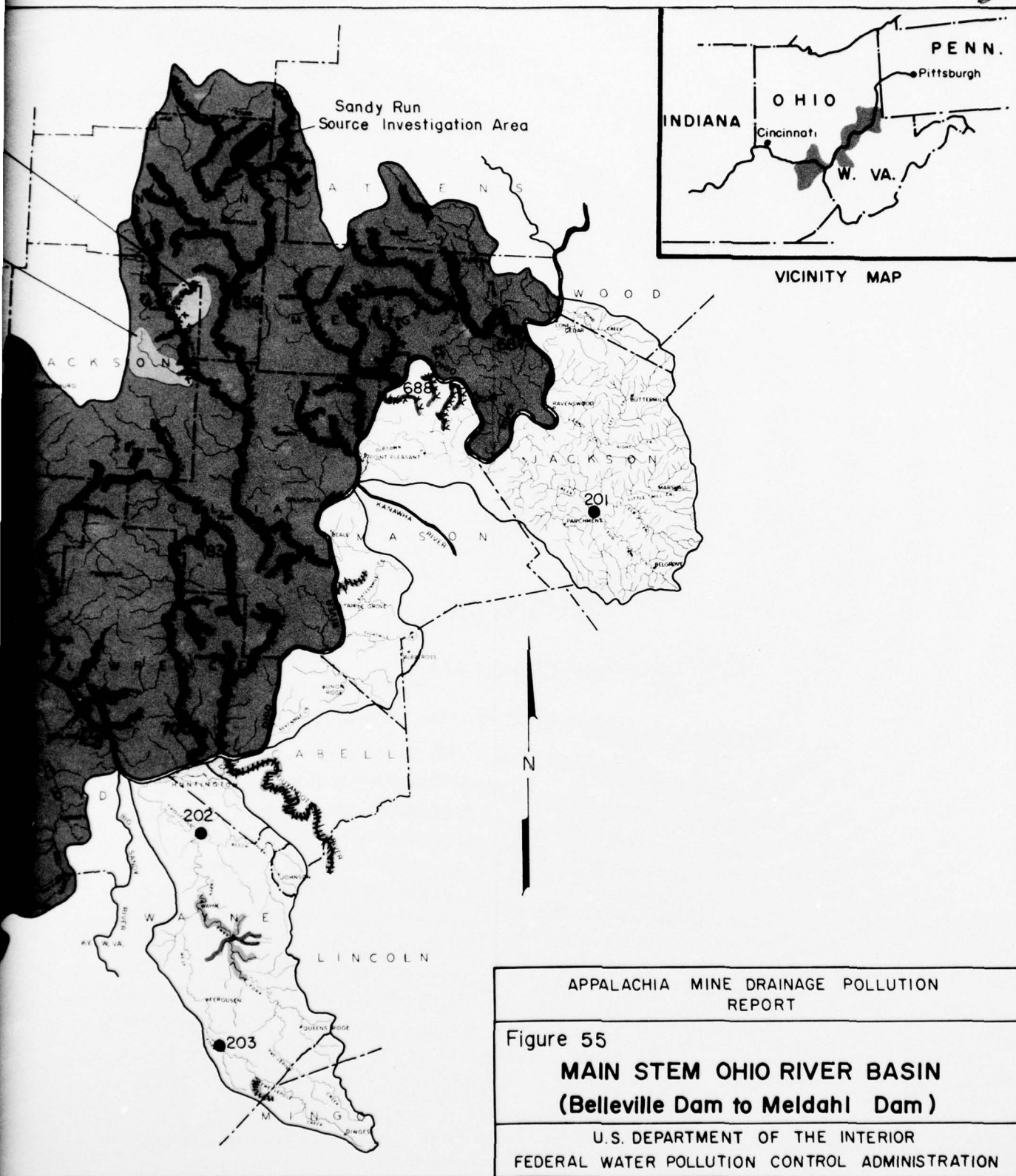
Figure 53
**MAIN STEM OHIO RIVER BASIN
(to New Cumberland Dam)**

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION



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Kentucky River Basin

Description

The Kentucky River basin is located in central Kentucky and is entirely within that state. The North Fork of the Kentucky River rises in Letcher County and the Kentucky River leaves Appalachia at the western border of Garrard County.

The Kentucky River basin is south of the glaciated portion of the Ohio River basin. Physical features of the basin are generally controlled by the erosional characteristics of the flat-lying paleozoic rocks that underlie the basin. The drainages of the South, Middle and North Forks of the Kentucky River all rise in the Eastern Kentucky coal field portion of the Appalachian Plateau.

Important coal reserves are present in Letcher, Leslie, Harlan, Knott, Perry, Breathitt, and Clay Counties. Coal bearing beds in the Kentucky basin are in Lee and Breathitt Formations of Pennsylvanian age. These coal-bearing rocks consist mainly of alternating beds of sandstone, siltstone, shale, coal and underclay. The Breathitt Formation is from 1,300 feet thick to 2,500 feet thick and contains 23 principal coal beds, including the Elkhorn No. 1, 2, and 3 coal beds and the Hazard coal beds (Huddle and others, 1963).

Coal has been produced in this area for over 100 years, but large-scale production has been limited to the past 50 years. Production is mostly from Letcher, Perry and Clay Counties. Locally, all coal beds are accessible by drift entry, which is the principal mining method in the area. Combination strip mining and auger mining is also widely practiced, particularly in Perry County. Large stripping operations are limited to a few areas.

Mine Drainage Sources and Their Effect on Stream Quality

The number of coal mine drainage pollution sources in the Kentucky River basin is not known. There are 10,000 acres of unreclaimed surface mined land in the basin.

Limited U.S. Geological Survey data from a water quality station at Hazard, Kentucky, indicate that the sulfate load in the North Fork at Hazard is in the order of 100 tons/day, 75 tons of which may result from acid mine drainage. Other sources of mine drainage below Hazard contribute in the order of 80 tons/day of sulfate to the Kentucky River. The total of 155 tons/day of sulfate considered to originate from mine drainage indicates the rate of formation of mine drainage acidity in the Kentucky River basin as compared to other areas discussed.

As shown in Figure 56 and by the analyses in Table 23 portions

of the Kentucky River and numerous tributary streams are continuously or intermittently polluted by mine drainage waters. A total of at least 495 miles of streams within the Kentucky River basin are considered significantly polluted by mine drainage on the basis of stream samples obtained during 1966 and on the basis of published reports and communication with other Federal and State agencies.

Mine drainage pollution occurs primarily in four portions of the Kentucky River basin in association with the mining activity in those areas. The four areas are the headwaters area of the North Fork of the Kentucky River in Letcher County, the Carrs Fork-Lotts Creek-Troublesome Creek area in Perry and Knott Counties, the Middle Fork Kentucky River area in Leslie County, and the South Fork Kentucky River area in Clay County (Fig. 56). The streams determined to be significantly affected by coal mine drainage in the Kentucky River basin are listed in Table 22.

Table 22 Streams in Kentucky River Basin Determined to be Significantly Polluted by Coal Mine Drainage.

<u>Stream</u>	<u>County</u>	<u>Map Station No. (Figure 56)</u>
*Quillen Fork	Letcher	560
Yonts Fork	"	561
Wright Fork	"	562
Millstone Creek	"	564
Smoot Creek	"	565
Rockhouse Creek	"	559, 548
North Fork Kentucky River (portions)	"	549
" " "	" Perry	536
" " "	" Breathitt	542
" " "	" Lee	514
Leatherwood Creek	Perry	546
Carrs Fork	Knott, Perry	558, 552
Irishman Creek	Knott	557
*Sassafras Creek	Knott	556
*Yellow Creek	Knott	555
*Stacy Branch	Knott	554
Acup Creek	Perry	553
Buckeye Creek	Perry	551
Buffalo Creek	Perry	544
*Raccoon Creek	Perry	543
Trace Creek	Knott	533
*Lotts Creek	Perry	535
*Jake Creek	Knott	532
*Big Creek	Perry	523
Buckhorn Creek	Breathitt	
Troublesome Creek	Breathitt	531
Quicksand Creek	Breathitt	516

<u>Stream</u>	<u>County</u>	<u>Map Station No.</u> <u>(Figure 56)</u>
Middle Fork Kentucky River	Leslie	526
Hurts Creek	Leslie	525
Cutshin Creek	Leslie	524
Red Bird River	Clay	527
Horse Creek	Clay	528
Goose Creek	Clay	529
Little Goose Creek	Clay	530
Grays Fork	Clay	No station
Kentucky River	Lee	
Kentucky River (portions)	Estill	510

*Indicates severely polluted streams

Severe mine drainage pollution was found to exist in small tributary streams such as Quillen Fork, Sassafras Creek, Yellow Creek, Stacy Branch, Raccoon Creek, Lotts Creek, Jake Creek and Big Creek (See Table 22 for station numbers and Figure 56 for map locations). The severity of mine drainage pollution in the Kentucky basin decreases rapidly downstream as such small tributaries merge with other slightly polluted or unpolluted streams, but the alkalinity of water in the Kentucky River may be reduced below desirable natural levels by acid mine water at least as far downstream as Irvine in Estill County (Sta. 510, Fig 56).

A. Headwaters Area North Fork Kentucky River

The Elkhorn No. 3 coal seam has been surface mined by rim cut in this area and refuse has been disposed of on the slopes below the mines. In many cases these refuse piles are on stream banks and drainage and silt from them enters directly into the streams.

Quillen Fork (Sta. 560) near the headwaters of the North Fork Kentucky River was acid throughout the study and had pH values between 2.7 and 4.9. Below the junction of Quillen Fork with Yonts Creek (Sta. 561) the acidity intermittently exceeded the alkalinity and concentrations of mine drainage indicators were high at all times.

Millstone Creek (Sta. 564), Smoot Creek (Sta. 564) and Rockhouse Creek (Stas. 559 and 548) were other streams found to be significantly affected by mine drainage in this area.

B. Carrs Fork-Lotts Creek-Troublesome Creek Area

In this area in Perry and Knott Counties, there has been extensive surface and underground mining of the Hazard No. 4 and Hazard No. 9 coal seams. There are presently six active deep mines, five

active auger mines, and two active combination strip and auger mines in the area. There are 11 known inactive underground mines with between 50 and 80 unsealed openings and 23 refuse piles, and two inactive surface mines in the area.

Various tributaries to Carrs Fork (Sta. 552) and Lotts Creek (Sta. 535) are continuously and severely polluted by coal mine drainage (Fig 56 and Table 23). Yellow Creek (Sta. 555), for example, had pH values ranging between 2.8 and 4.6 and average acidity of 566 mg/l, with zero alkalinity. Carrs Fork and Lotts Creek are less acid than some of their tributaries, but the average concentrations of various indicators such as iron and manganese are well above desirable limits in these two streams.

It is believed that the most severe pollution in this area occurs during periods of high runoff, when slugs of pollution enter the streams. These conditions were not encountered at the times of sampling.

C. Middle Fork Kentucky River Area

In this area near Hyden in Leslie County there are only a few small mines in operation and these are mainly underground ones.

Stream pollution in this area is not severe in comparison with the other areas described. However, periodic degradation of some streams is evidenced by some samples collected at stations 524 (Cutshin Creek), 525 (Hurts Creek), and 526 (Middle Fork Kentucky River) in which concentrations of mine drainage indicators exceeded desirable levels.

D. South Fork Kentucky River

In the drainage area of South Fork Kentucky River near Manchester, Kentucky, there has been extensive surface and underground mining of the Horse Creek coal seam, and resultant mine drainage pollution of streams in the area.

Horse Creek (Sta. 528) and Little Goose Creek (Sta. 530), tributaries to Goose Creek, were polluted throughout the study. Generally, pH values in these streams were below 6.5 and minimum values were 4.2 in Horse Creek and 5.8 in Goose Creek. Goose Creek and sections of the South Fork below Manchester are reported to be acid on occasions. Fish kills are reported to have resulted from mine drainage pollution in Goose Creek.

Table 23 - Stream Quality Data, Kentucky River Basin

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Manganese (mg/l)	Aluminum (mg/l)	Flow (cfs)
503	1	6.4	0.0	42.0	152.0	72.0	0.4	--	--	--
	Min.									
	Max.									
	Avg.									
504	1	7.0	8.0	196.0	240.0	55.0	0.2	--	--	--
	Min.									
	Max.									
	Avg.									
505	1	7.6	6.0	36.0	92.0	10.0	3.0	--	--	--
	Min.									
	Max.									
	Avg.									
510	1	7.0	33.0	26.0	84.0	30.0	2.2	--	--	--
	Min.									
	Max.									
	Avg.									
513	1	7.6	19.0	20.0	64.0	15.0	8.1	--	--	--
	Min.									
	Max.									
	Avg.									
514	1	6.6	13.0	21.0	76.0	22.0	5.8	--	--	--
	Min.									
	Max.									
	Avg.									
516	1	6.8	6.0	58.0	80.0	18.0	0.7	--	--	--
	Min.									
	Max.									
	Avg.									
523	7	4.1	175.0 76.8	0.0 20.0 4.8(6)*	475.0 305.8(6)	696.0 326.7(6)	221.0 34.8	12.0 5.1(6)	143.0 29.9(6)	83.0 28.5
	Min.									
	Max.									
	Avg.									
524	6	5.9	42.0 12.5	22.0 76.0 39.6(5)	144.0 76.8(5)	220.0 60.4(5)	3.9 1.0	0.1 0.1(5)	5.0 2.3(5)	20.0 12.2(4)
	Min.									
	Max.									
	Avg.									
525	6	6.0	76.0 18.3	5.0 108.0 67.8(5)	180.0 139.6(5)	204.0 122.8(5)	6.7 1.7	0.1 0.1(5)	13.0 4.5(5)	5.0 1.5
	Min.									
	Max.									
	Avg.									

*(6) Indicates the number of samples used in averages when other than the maximum.

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Table 23 - Stream Quality Data, Kentucky River Basin (cont'd)

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Manganese (mg/l)	Aluminum (mg/l)	Flow (cfs)
526	1	6.2	49.0	16.0	44.0	6.0	0.6	--	--	--
	Min.									
	Max.									
	Avg.									
527	1	6.2	36.0	20.0	84.0	9.0	0.2	--	--	--
	Min.									
	Max.									
	Avg.									
528	7	4.2	132.0 40.8	0.0 18.0 9.0(6)*	272.0 147.5(6)	460.0 128.2(6)	4.5 2.8	9.7 4.2(6)	7.0 2.9(6)	61.0 12.0
	Min.									
	Max.									
	Avg.									
529	7	5.8	64.0 17.6	10.0 42.0 20.0(6)	176.0 86.3(6)	200.0 52.7(6)	1.8 1.0	3.3 1.0(6)	2.2 0.7(6)	710.0 163.9(5)
	Min.									
	Max.									
	Avg.									
530	7	5.5	60.0 16.1	0.0 15.0 9.8(6)	188.0 147.0(6)	230.0 103.3(6)	1.3 0.6	3.3 2.0(6)	2.3 1.3(6)	98.0 21.8
	Min.									
	Max.									
	Avg.									
531	6	4.3	96.0 25.5	0.0 26.0 10.8(5)	328.0 188.8(5)	210.0 118.6(5)	20.0 4.2	3.5 1.3(5)	18.0 5.8(5)	150.0 42.7
	Min.									
	Max.									
	Avg.									
532	7	4.2	340.0 85.8	54.0 17.3(6)	728.0 506.7(6)	750.0 459.7(6)	9.7 3.8	2.4 1.6(6)	17.0 6.6(6)	12.9 4.3
	Min.									
	Max.									
	Avg.									
533	7	5.2	250.0 56.8	1.0 120.0 65.5(6)	452.0 322.7(6)	500.0 269.7(6)	6.0 2.2	1.3 0.8(6)	10.0 3.4(6)	18.5 5.5
	Min.									
	Max.									
	Avg.									
534	7	3.0	860.0 277.4	0.0 30.0 6.3(6)	784.0 478.0(6)	1820.0 968.7(6)	70.0 24.2	11.0 6.3(6)	33.0 21.3(6)	72.0 25.2
	Min.									
	Max.									
	Avg.									
535	7	3.2	405.0 129.1	0.0 30.0 9.2(6)	644.0 425.3(6)	780.0 471.7(6)	39.0 11.7	8.5 4.5(6)	29.0 15.3(6)	91.0 34.0
	Min.									
	Max.									
	Avg.									

*(6) Indicates the number of samples used in averages when other than the maximum.

Table 23 - Stream Quality Data, Kentucky River Basin

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Manganese (mg/l)	Aluminum (mg/l)	Flow (cfs)
536	7	5.8	67.0 16.0	18.0 102.0 40.5(6)*	256.0 150.7(6)	220.0 103.3(6)	20.0 4.8	0.6 0.2(6)	18.0 5.6(6)	2050.0 488.0(5)
541	1	6.3	48.0	27.0	88.0	60000.0	0.5	--	--	--
542	1	6.0	7.0	27.0	120.0	80.0	0.2	--	--	--
543	7	3.6	270.0 102.3	0.0 20.0 3.3(6)	594.0 416.2(6)	750.0 385.5(6)	8.2 4.4	7.2 2.9(6)	11.7 6.3(6)	10.5 2.2
544	7	3.2	268.0 193.0	0.0 10.0 2.3(6)	676.0 432.3(6)	1450.0 821.0(6)	24.0 10.6	9.7 7.9(6)	26.0 18.6(6)	7.1 2.4
545	7	6.1	30.0 10.8	22.0 96.0 59.2(6)	144.0 97.3(6)	50.0 14.7(6)	1.5 0.5	0.1 0.1(6)	2.4 1.0(6)	17.5 5.1
546	1	6.5	0.0	37.0	68.0	37.0	--	--	--	--
547	1	6.4	0.0	38.0	84.0	32.0	--	--	--	--
548	1	6.5	4.0	13.0	124.0	134.0	--	--	--	--
549	1	6.1	0.0	42.0	104.0	92.0	--	--	--	--

*(6) Indicates the number of samples used in averages when other than the maximum.

Table 23 - Stream Quality Data, Kentucky River Basin

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Manganese (mg/l)	Aluminum (mg/l)	Flow (cfs)
550	1	6.3	0.0	37.0	100.0	37.0	--	--	--	--
	Min.									
	Max.									
	Avg.									
551	6	5.4	35.0	26.0	332.0	280.0	3.6	0.6	4.0	6.4
	Min.		7.3	106.0	237.2(5)	130.6(5)	1.1	0.3(5)	1.9(5)	1.5
	Max.			62.4(5)*						
	Avg.									
552	7	5.2	64.0	4.0	302.0	350.0	9.0	2.5	8.4	201.0
	Min.		21.8	64.0	167.0(6)	157.0(6)	2.7	1.1(6)	2.6(6)	74.0
	Max.			21.8(6)						
	Avg.									
553	6	3.7	180.0	0.0	1032.0	1100.0	75.0	4.8	5.4	5.8
	Min.		55.5	38.0	532.0(5)	532.0(5)	14.0	3.0(5)	3.6(5)	1.8
	Max.			9.8(5)						
	Avg.									
554	7	2.9	452.0	0.0	390.0	640.0	49.0	4.6	40.0	7.3
	Min.		240.7	30.0	317.0(6)	503.3(6)	26.7	4.1(6)	25.3(6)	2.2
	Max.			6.7(6)						
	Avg.									
555	7	2.7	910.0	0.0	500.0	970.0	88.0	8.2	47.0	5.5
	Min.		565.8	1.0(6)	434.3(6)	696.0(6)	46.3	7.1(6)	29.7(6)	1.9
	Max.									
	Avg.									
556	7	3.1	464.0	0.0	456.0	430.0	21.5	9.3	30.1	4.8
	Min.		159.8	68.0	259.3(6)	211.7(6)	4.2	5.4(6)	13.1(5)	1.9
	Max.			11.3(6)						
	Avg.									
557	1	5.5	38.0	19.0	88.0	90.0	0.3	--	--	4.9
	Min.									
	Max.									
	Avg.									
558	8	5.5	100.0	19.0	116.0	464.0	2.4	0.2	4.3	88.0
	Min.		22.5	106.0	88.3(6)	103.5(6)	0.9(7)	0.1(6)	2.0(6)	29.8(7)
	Max.			52.8(7)						
	Avg.									
559	7	4.4	145.0	0.0	488.0	1730.0	24.8	3.8	8.4	32.0
	Min.		37.1	110.0	223.7(6)	448.8(6)	8.7	1.6(6)	4.7(6)	12.1(6)
	Max.			32.5(6)						
	Avg.									

*(5) Indicates the number of samples used in averages when other than the maximum.

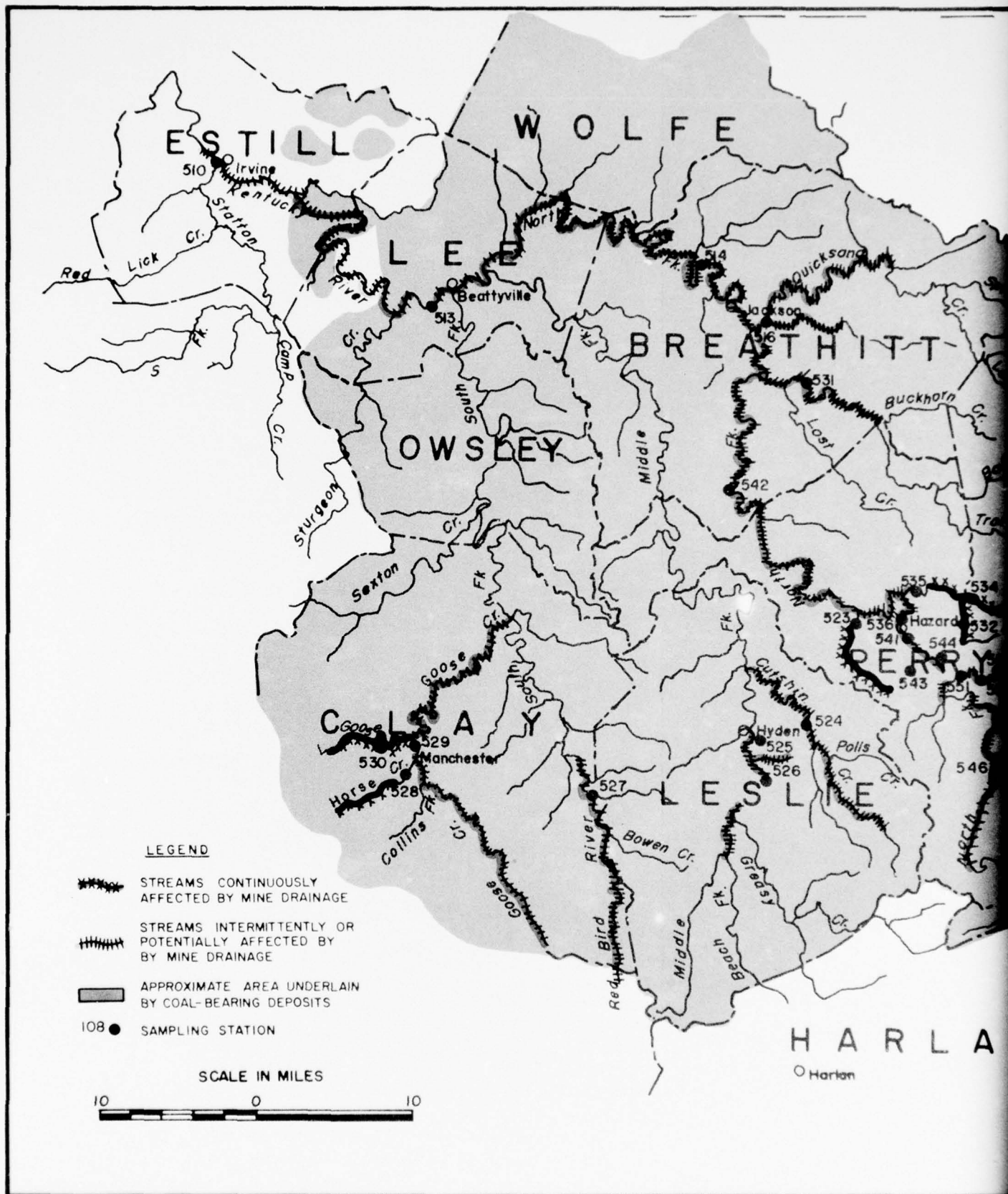
Table 23 - Stream Quality Data, Kentucky River Basin

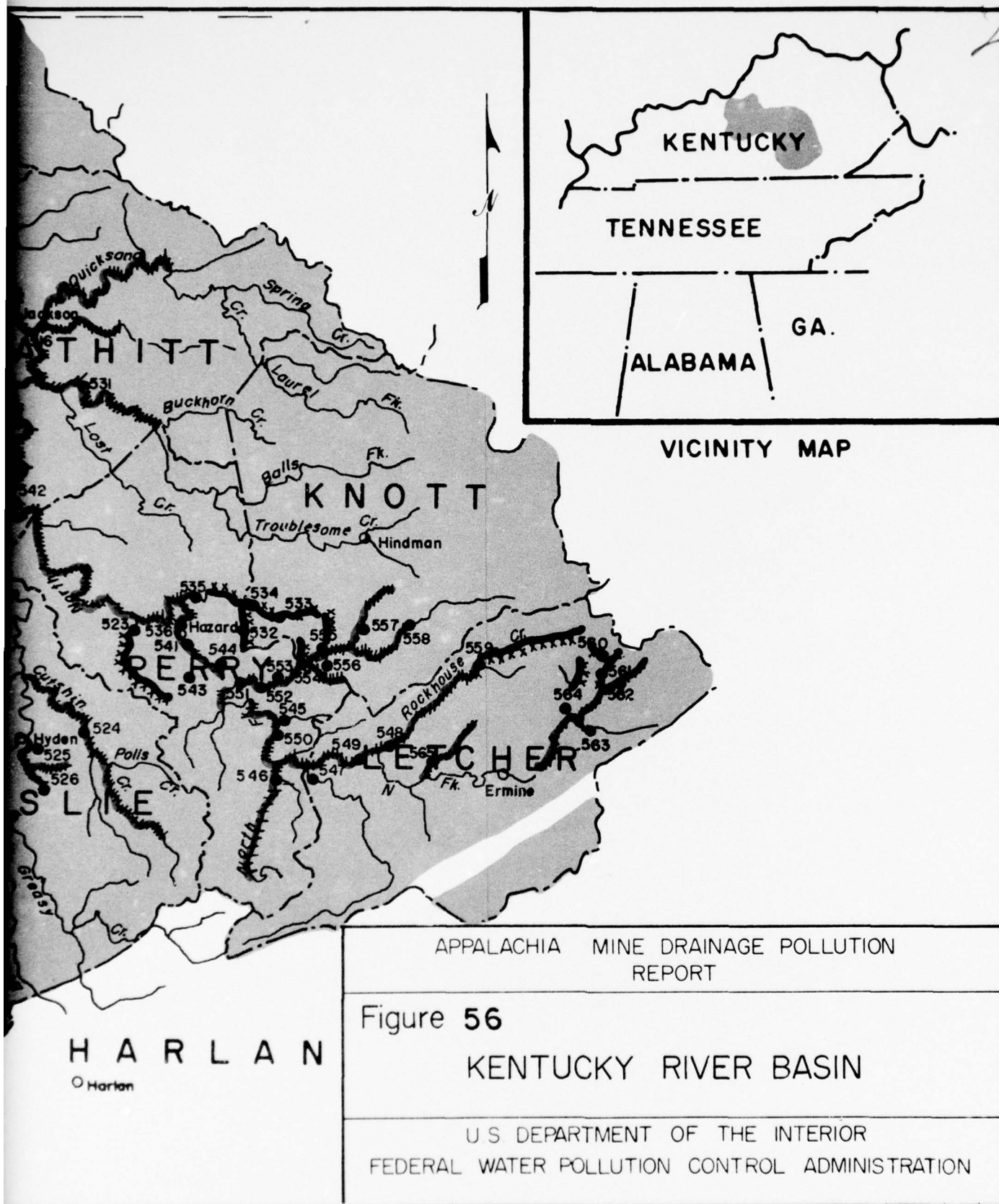
5

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Manganese (mg/l)	Aluminum (mg/l)	Flow (cfs)
560	6	3.0	668.0 375.0	0.0 50.0 8.3	508.0 312.0	840.0 555.0	113.5 41.3	7.0 4.1	58.5 33.4	2.1 1.1
561	7	5.0	248.0 48.5(6)*	0.0 296.0 140.3(6)	348.0 250.0(6)	460.0 315.2(6)	116.0 20.3	3.4 1.1(6)	43.2 13.8(6)	8.3 3.9
562	6	6.5	25.0 4.7	124.0 296.0 186.4(5)	276.0 210.4(5)	200.0 138.4(5)	31.7 5.6	1.4 0.4(5)	23.0 5.6(5)	10.3 4.5(5)
563	1	6.6	0.0	78.0	144.0	80.0	0.2	--	--	--
564	6	6.5	6.0 1.8	106.0 230.0 157.2(5)	388.0 292.0(5)	688.0 375.6(5)	38.7 6.9	3.1 0.8(5)	48.8 10.3(5)	13.8 6.5
565	6	5.6	84.0 25.0	10.0 82.0 32.0(5)	296.0 197.6(5)	308.0 165.2(5)	93.5 17.8	3.4 1.3(5)	160.0 35.0(5)	9.5 3.5
620	1	7.1	16.0	209.0	260.0	20.0	0.2	--	--	--
621	1	6.9	0.0	137.0	160.0	30.0	0.3	--	--	--

*(6) Indicates the number of samples used in averages when other than the maximum.

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Cumberland River Basin

Description

The Cumberland River is formed by the confluence of the Poor and Clover Forks near Harlan, Kentucky in Appalachia (Fig. 57). From that point, it flows southwesternly into Tennessee, leaving Appalachia at the western border of Smith County, Tennessee. The total area of the Cumberland basin is 17,914 square miles about 60 percent of which is in Appalachia. The Cumberland basin is bounded on the south by the Tennessee River basin and on the north by the Kentucky and Green River basins.

The upper Cumberland basin, above Lake Cumberland, is in the Cumberland Mountains, where the Cumberland and its tributaries flow in deep narrow valleys and have gradients of 10 to 12 feet per mile. In the remainder of the Cumberland basin in Appalachia, the terrain is hilly and the streams have gradients of 3 to 5 feet per mile.

The main coal producing counties in the Kentucky portion of the Cumberland basin are Harlan, Bell, Knox, McCreary, Whitley, Laurel, Jackson, Pulaski and Rockcastle. Important coal producing counties in Tennessee are Clairborne, Campbell, Scott, Fentress and Overton.

In the Kentucky portion of the Cumberland basin, coal is contained in the Lee and Breathitt Formations of Pennsylvanian age. The Lilly coal bed forms the boundary between these geologic units, the Lee Formation being the older. The Hazard and Harlan coal beds occur in the Breathitt Formation. In the Tennessee portion of the Cumberland basin the main coal bearing beds are in Gizzard, Crab Orchard Mountain, Crooked Fork, Slatestone, Indian Bluff, Gravel Gap and Redoak Mountain Groups (Luther, 1959).

Coal mining in the Cumberland basin began in the late 1700's, and has varied in intensity since that time, peak production periods coming in the period from 1910 through the middle 1940's. Production today is considerably less than during peak periods.

Coal mining in this area has been, much as in the Kentucky basin, primarily by drift mining. Strip mining has been particularly important in Bell, Knox, and Laurel Counties, Kentucky, and Fentress County, Tennessee. Combination strip and auger mining is particularly important in Harlan County, Kentucky. Contour strip mining has been widely practiced in preparation for more extensive underground mining.

Mine Drainage Sources and Their Effect on Stream Quality

No estimate of the number of mine drainage sources in the Cumberland River basin is available. There are 29,000 acres of unreclaimed surface mined land in the basin.

An average sulfate load of 225 tons/day was carried by the Cumberland River at Williamsburg, Kentucky (Sta. 608) during the years 1952-1959 (Fig. 58). Of this total, 130 tons/day is considered to have resulted from mine drainage. At least 70 tons/day of sulfate is estimated to be contributed by mine drainage sources downstream from Williamsburg on the basis of 1966 stream sampling data. The minimum total of 200 tons/day of sulfate estimated to originate in mine drainage indicates the rate of formation of mine drainage acidity in the Cumberland basin.

Figure 57 and the analyses in Table 25 show that the upper few miles of the Cumberland River and numerous tributaries as far downstream as the West Fork of the Obey River in Overton County are continuously or intermittently polluted by mine drainage waters. A total of at least 510 miles of streams within the Appalachian portion of the Cumberland River basin are considered significantly polluted by mine drainage on the basis of stream samples obtained during 1966 and on the basis of published reports and communication with other Federal and State agencies. The streams considered to be significantly affected by mine drainage are indicated in Table 24.

Table 24 - Streams in the Appalachian Portion
of the Cumberland River Basin Determined to be
Significantly Polluted by Coal Mine Drainage

<u>Stream</u>	<u>County</u>	<u>Map Station Number (Fig. 57)</u>
Poor Fork	Letcher, Ky.	
Cumberland River	Harlan, Ky.	566, 568
Looney Creek	Harlan, Ky.	567
*Cranks Creek	Harlan, Ky.	572
Martins Fork	Harlan, Ky.	571
Puckett Creek	Harlan and Bell, Ky.	575
Stony Fork	Bell, Ky.	597, 595
Bennets Fork	Clairborne, Tenn. and Bell, Ky.	596
Yellow Creek	Bell, Ky.	594
Cumberland River	Bell, Ky.	576, 580
Straight Creek	Bell and Harlan, Ky.	579, 577
*Left Fork Straight Crk.	Bell, Ky.	578
Middle Fork Stinking Crk.		583

Table 24 (cont'd)

<u>Stream</u>	<u>County</u>	<u>Map Station Number (Fig. 57)</u>
Brush Creek	Knox, Ky.	581
Patterson Creek	Whitley, Ky.	607
*Clear Fork	Clairborne, Tenn.	598
Straight Creek	Bell, Ky.	599
Clear Fork	Whitley, Ky.	606
Clear Fork	Clairborne and Campbell, Tenn.	598, 600
Stinking Creek	Campbell, Tenn.	604
Hickory Creek	Campbell, Tenn.	603, 602
White Oak Creek	Campbell, Tenn.	601
Pleasant Run	Whitley, Ky.	612
Jellico Creek	Whitley, Ky.	611
Marsh Creek	McCreary, Ky.	614
*Raccoon Creek	Laurel, Ky.	539
Little Raccoon Creek	Laurel, Ky.	538
Wood Creek	Laurel, Ky.	537
Beaver Creek	McCreary, Ky.	630
Hall Creek	Scott, Tenn.	642
Brimstone Creek	Scott, Tenn.	640
Buffalo Creek	Scott, Tenn.	637
*Flat Creek	Scott, Tenn.	636
*Sulphur Creek	Scott, Tenn.	635
Phillips Creek	Scott, Tenn.	638
New River	Scott, Tenn.	639
Davis Creek	Fentress and Scott, Tenn.	641
*Rock Creek	McCreary, Ky.	617
South Fork	McCreary, Ky.	615
Wolf Creek	McCreary, Ky.	616
*Meadow Creek	Putnam, Tenn.	650
W. Fork Obey River	Overton, Tenn.	645
*Cub Creek	Overton, Tenn.	646
*Little Laurel Creek	Fentress, Tenn.	647
*E. Fork Obey River	Overton and Fentress, Tenn.	648, 649
*Officer Creek	Putnam, Tenn.	651

***Severely Polluted Streams**

Beginning in the headwaters area of the Cumberland basin, significant mine drainage pollution is first found in the Poor Fork (Sta. 566), where iron concentrations averaged nearly 3 mg/l and sulfate concentrations as high as 460 mg/l were measured.

There has been extensive mining of the Mason coal seam in the Cranks Creek watershed Harlan County, Kentucky, and the resultant mine drainage significantly affects Cranks Creek (Sta. 572) and Martins Fork (Stas. 570 and 571). Values of pH as low as 4.2 were measured in Cranks Creek.

Proceeding downstream the next major damaged area is the watershed of Yellow Creek, where extensive surface and underground mining in the Stony Fork (Stas. 597 and 595) and Bennetts Fork (Sta. 596) watersheds has caused intermittent pollution of these streams.

In the Straight Creek watershed, Bell and Harlan Counties, Kentucky, there has been extensive mining of the Crockett coal seam in the Left Fork drainage (Sta. 578) and of the Hazard No. 9 and Hazard No. 7 coal seams in the Right Fork drainage. Mine drainage pollution is most severe in the Left Fork, where pH values as low as 4.2 were measured.

In the Clear Fork drainage basin, Clairborne and Campbell Counties, Tennessee, and Whitley County, Kentucky, Straight Creek (Sta. 599), White Oak Creek (Sta. 601) Hickory Creek (Stas. 602 and 603), and Stinking Creek (Sta. 604) as well as the Clear Fork (Stas. 598, 600, and 606) were observed to be significantly degraded by mine drainage.

Along the Clear Fork, recent mining appears to be underground mining in Tennessee, but a coal processing plant and several refuse piles are contributing pollution into the Clear Fork in Kentucky.

In the Hickory Creek watershed, almost the entire rim of the White Oak Creek drainage basin has been strip mined and the waste has been cast down the slopes. The measured pH values in White Oak Creek (Sta. 601) did not fall below 5.8, but the stream appeared to be devoid of aquatic life. Values of pH as low as 4.2 were measured in Stinking Creek (Sta. 604).

Pleasant Run and Jellico Creek in the lower Jellico Creek basin are severely degraded by mine drainage. In the portion of Pleasant Run between stations 612 and 613 (Fig. 57) the Stearns coal seam has been strip mined in the flood plain and across the stream. The pH at station 612 fell as low as 2.8 and did not exceed 4.0.

Inactive underground and surface mines that remain after mining of the Lilly coal seam are the source of mine drainage pollution in Raccoon Creek (Sta. 538) and Little Raccoon Creek (Sta. 539). Although extensive mining ceased some time ago, these streams are still acid most of the time. The pH values in Raccoon Creek ranged generally between 4.5 and 6.2 and those in Little Raccoon Creek ranged generally between 4.8 and 5.9.

In the New River drainage basin, Tennessee, many small streams are severely polluted by mine drainage that originates chiefly in inactive mines. Data from sampling stations on Flat Creek (Sta. 636) and Sulphur Creek (Sta. 635) exemplify the

severity of pollution in this area. The pH values measured at these stations ranged between 2.9 and 4.8. Pollution from the minor tributaries periodically lowers the alkalinity and pH in the New River (Sta. 639) to below desirable levels and increases the concentration of iron to above desirable levels.

Relatively serious mine drainage pollution exists in the Cumberland National Forest, McCreary County, Kentucky. Mining has been carried on in the Rock Creek drainage area since the early 1900's and most of the pollution load is apparently from refuse piles in this area. Data from sampling station 617 on Rock Creek indicate that the pH of this stream is below 6.0 most of the time and values as low as 3.3 were measured.

The area most severely degraded by mine drainage in Tennessee is the Obey River basin. In the West Fork watershed, Cub Creek (Sta. 646) is the only highly acid stream. At and just below the junction of Cub Creek with the West Fork, damage to the West Fork is apparent, particularly from iron precipitates.

The East Fork of the Obey River is severely degraded by mine drainage and is devoid of fish and other aquatic life from its headwaters to near the point where it enters Dale Hollow Reservoir, a distance of about 30 miles. Measured pH values in the East Fork did not exceed 3.4 at station 648 and were as low as 4.3 at station 643 just above Dale Hollow Reservoir. Highly polluted tributaries to the East Fork include Meadow Creek (Sta. 650), Little Laurel Creek (Sta. 647), and Officer Creek (Sta. 651). Serious reduction of fish populations in the East Fork of Dale Hollow have been reported by the Tennessee Department of Fish and Game.

Table 25 - Water Quality Data, Cumberland River Basin

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Manganese (mg/l)	Aluminum (mg/l)	Flow (cfs)
537	Min.	5.9	63.0 *	8.0	200.0	186.0	1.4	2.2	1.5	4.3
	Max.									
	Avg.									
538	Min.	4.8	165.0	2.0	204.0	238.0	1.9	5.5	1.9	13.0
	Max.									
	Avg.									
539	Min.	4.5	256.0	0.0	214.0	696.0	1.3	10.4	7.5	35.0
	Max.									
	Avg.									
540	Min.	6.1	38.0	15.0	52.0	32.0	1.0	-	-	-
	Max.									
	Avg.									
566	Min.	6.0	5.7	64.0	132.0	460.0	10.9	22.5	2.0	914
	Max.									
	Avg.									
567	Min.	7.1	0.0	199.0	120.0	80.0	0.2	-	-	-
	Max.									
	Avg.									
568	Min.	6.4	0.0	52.0	60.0	38.0	0.2	-	-	-
	Max.									
	Avg.									
569	Min.	6.6	0.0	43.0	72.0	64.0	0.2	-	-	-
	Max.									
	Avg.									
570	Min.	6.6	0.0	41.0	48.0	45.0	0.4	-	-	-
	Max.									
	Avg.									
571	Min.	5.6	88.0	26.0	84.0	30.0	1.6	0.2	2.5	54.0
	Max.									
	Avg.									

*(5) Indicates the number of samples used in averages when other than the maximum.

Table 25 - Water Quality Data, Cumberland River Basin (cont'd)

2

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Manganese (mg/l)	Aluminum (mg/l)	Flow (cfs)
572	Min. Max. Avg.	4.2	325.0 82.7	0.0 34.0 11.8(5)*	264.0 182.0(5)	410.0 281.2(5)	21.6 5.1	4.8 1.5(5)	49.0 19.3(5)	5.4 2.7(5)
573	Min. Max. Avg.	6.7	42.0	6.0	64.0	48.0	0.8	-	-	-
574	Min. Max. Avg.	6.3	47.0	56.0	56.0	67.0	0.8	-	-	-
575	Min. Max. Avg.	6.9	31.0	79.0	116.0	108.0	0.2	-	-	-
576	Min. Max. Avg.	6.4	50.0	44.0	60.0	43.0	0.5	-	-	-
577	Min. Max. Avg.	5.1	70.0 22.4	18.0 96.0 39.8(6)	140.0 110.7(6)	113.0 79.0(6)	1.6 0.7	0.7 0.4(6)	2.7 1.0(6)	420.0 96.6
578	Min. Max. Avg.	4.2	88.0 40.4	2.0 94.0 24.2	256.0 158.0(6)	525.0 181.3(6)	3.7 2.5	3.4 1.6(6)	6.0 2.9(6)	150.0 31.5
579	Min. Max. Avg.	5.3	64.0 22.7	4.0 40.0 22.0(5)	180.0 107.2(5)	96.0 47.6(5)	1.2 0.6	3.6 1.0(5)	2.0 1.0(5)	55.0 21.1(4)
580	Min. Max. Avg.	6.7	38.0	44.0	56.0	44.0	0.4	-	-	-
581	Min. Max. Avg.	6.3	33.0	50.0	88.0	44.0	0.6	-	-	-

*(5) Indicates the number of samples used in averages when other than the maximum.

Table 25 - Water Quality Data, Cumberland River Basin (cont'd)

Map Station No.	Min. Max. Avg.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Manganese (mg/l)	Aluminum (mg/l)	Flow (cfs)
582		1	6.5	7.0	38.0	84.0	37.0	0.2	-	-	-
583		5	5.9	58.0 15.8	22.0 30.0 26.5(4)*	60.0 45.0(4)	26.0 10.2(4)	2.6 1.6	3.3 1.0(4)	2.4 1.0(4)	20.0 7.6
584		1	6.4	0.0	38.0	52.0	37.0	0.3	-	-	-
585		1	6.2	0.0	29.0	44.0	20.0	0.3	-	-	-
586		1	6.3	6.0	21.0	28.0	20.0	0.3	-	-	-
587		1	6.3	3.0	25.0	40.0	19.0	0.3	-	-	-
588		1	6.4	0.0	50.0	60.0	22.0	0.2	-	-	-
589		1	6.7	0.0	117.0	128.0	12.0	0.2	-	-	-
590		1	6.9	0.0	128.0	140.0	28.0	0.2	-	-	-
591		1	6.8	0.0	96.0	96.0	15.0	0.2	-	-	-

*(4) Indicates the number of samples used in averages when other than the maximum.

Table 25 - Water Quality Data, Cumberland River Basin (cont'd)

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Manganese (mg/l)	Aluminum (mg/l)	Flow (cfs)
592	1	6.5	0.0	44.0	64.0	20.0	0.2	-	-	-
593	1	6.4	9.0	26.0	92.0	21.0	0.3	-	-	-
594	1	6.7	0.0	71.0	156.0	114.0	0.3	-	-	-
595	6	5.9	55.0 10.5	20.0 52.0 35.2(5)*	264.0 186.4(5)	170.0 130.4(5)	18.0 3.3	0.7 0.5(5)	2.0 1.0(5)	29.0 10.3(5)
596	6	6.1	55.0 14.3	44.0 140.0 97.0(5)	316.0 257.6(5)	200.0 158.6(5)	14.0 4.0	0.8 0.4(5)	18.0 5.9(5)	35.0 12.8(5)
597	6	4.8	124.0 24.8	2.0 86.0 48.2(5)	272.0 204.0(5)	400.0 180.8(5)	5.1 2.6	0.5 0.2(5)	3.8 1.7(5)	5.0 2.4(5)
598	7	5.6	52.0 26.2(6)	12.0 28.0 19.4	328.0 233.3(6)	420.0 224.5(6)	33.0 9.5	3.6 1.9(6)	26.0 7.1(6)	35.0 12.0
599	6	5.5	168.0 33.0	2.0 30.0 17.2(5)	212.0 113.2(5)	200.0 118.0(4)	3.6 1.1	1.9 1.0(5)	3.4 1.8(5)	24.0 7.6
600	6	5.7	56.0 13.8	20.0 66.0 41.4(5)	368.0 208.8(5)	220.0 133.8(5)	9.2 2.5	1.0 0.7(5)	8.1 2.8(5)	102.0 30.6
601	6	5.8	125.0 23.5	38.0 216.0 125.4(5)	224.0 179.2(5)	305.0 168.1(5)	9.5 5.1	4.2 3.4(5)	5.8 3.7(5)	20.0 5.6

*(5) Indicates the number of samples used in averages when other than the maximum.

Table 25 - Water Quality Data, Cumberland River Basin (cont'd)

5

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Manganese (mg/l)	Aluminum (mg/l)	Flow (cfs)
602	Min. Max. Avg.	6.2	2.0 1.0	35.0 35.0(1)*	100.0 100.0(1)	110.0 110.0(1)	0.2 0.2	-	-	33.0 33.0
603	Min. Max. Avg.	4.4	200.0 41.1	0.0 10.0 5.5(6)	156.0 122.7(6)	416.0 145.2(5)	3.5 1.1	4.9 2.5(6)	8.5 2.3(6)	220.0 46.6
604	Min. Max. Avg.	4.5	156.0 31.3	0.0 11.0 5.5(6)	172.0 99.3(6)	220.0 68.3(6)	2.0 0.8	4.7 1.3(6)	5.8 1.5(6)	140.0 33.9
605	Min. Max. Avg.	6.3	0.0	69.0	136.0	104.0	-	-	-	-
606	Min. Max. Avg.	5.5	88.0 16.0	10.0 38.0 26.2(5)	128.0 104.8(5)	140.0 76.0(5)	11.0 2.9	1.4 0.7(5)	22.0 6.3(5)	160.0 74.8
607	Min. Max. Avg.	5.8	10.0 2.5(4)	4.0 182.0 75.4	180.0 137 (4)	125.0 94.7(4)	1.4 0.6	0.4 0.2(4)	2.3 1.1(4)	8.0 4.3(3)
608	Min. Max. Avg.	6.4	0.0	32.0	56.0	40.0	0.9	-	-	-
609	Min. Max. Avg.	6.4	0.0	32.0	92	78	1.2	-	-	-
610	Min. Max. Avg.	6.5	18.0	31.0	56.0	42.0	1.2	-	-	-
611	Min. Max. Avg.	4.9	120.0 24.2	6.0 38.0 17.0(5)	92.0 67.2(5)	78.0 35.0(5)	1.4 0.4	0.8 0.3(5)	2.2 1.4(5)	31.0 16.4(5)

*(1) Indicates the number of samples used in averages when other than the maximum.

Table 25 - Water Quality Data, Cumberland River Basin (cont'd)

6

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Manganese (mg/l)	Aluminum (mg/l)	Flow (cfs)
612	7	2.8	340.0 197.2(6)*	0.0 87.0 12.4	252.0 211.8(6)	420.0 253.0(6)	16.0 8.6	11.2 8.7(6)	14.9 9.5(6)	14.0 3.3
613	7	4.3	112.0 67.5(6)	0.0 14.0 3.0	192.0 156.0(6)	160.0 114.6(5)	1.5 0.8	7.6 6.0(6)	5.4 2.3(6)	11.1 2.4
614	6	5.9	58.0 14.2	14.0 18.0 15.6(5)	80.0 61.2(5)	28.0 21.8(5)	2.5 1.1	1.1 0.5(5)	3.6 1.8(5)	7.8 3.9(5)
615	1	6.2	10.0	10.0	48.0	46.0	-	-	-	-
616	6	6.0	10.0 4.8	31.0 102.0 65.8(5)	164.0 124.8(5)	60.0 47.8(5)	0.7 0.2(5)	0.2 0.1(4)	2.1 1.4(5)	5.6 2.7
617	7	3.3	250.0 113.0(6)	0.0 18.0 3.7	156.0 107.3(6)	140.0 77.3(6)	15.0 7.5	1.3 0.7(6)	9.6 4.3(6)	440.0 75.3
618	1	6.8	-	-	-	-	-	-	-	-
619	1	6.6	6.0	44.0	64.0	36.0	0.2	-	-	-
628	1	6.8	0.0	52.0	64.0	20.0	0.2	-	-	-
629	1	7.5	0.0	129.0	220.0	53.0	0.2	-	-	-

*(6) Indicates the number of samples used in averages when other than the maximum.

Table 25 - Water Quality Data, Cumberland River Basin (cont'd)

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Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Manganese (mg/l)	Aluminum (mg/l)	Flow (cfs)
630	1	7.6	0.0	145.0	168.0	12.0	0.2	-	-	-
	Min.									
	Max.									
	Avg.									
631	1	6.5	44.0	38.0	60.0	22.0	0.2	-	-	-
	Min.									
	Max.									
	Avg.									
632	1	6.9	8.0	37.0	60.0	13.0	0.2	-	-	-
	Min.									
	Max.									
	Avg.									
633	1	8.2	0.0	78.0	76.0	40.0	0.2	-	-	-
	Min.									
	Max.									
	Avg.									
634	1	7.2	0.0	76.0	88.0	22.0	0.5	-	-	1.2
	Min.									
	Max.									
	Avg.									
635	7	2.9	780.0 353.1	0.0 0.0	448.0 290.0(6)*	530.0 260.0(6)	44.0 26.1	10.6 8.5(6)	78.0 28.7(6)	6.0 1.1
	Min.									
	Max.									
	Avg.									
636	7	3.2	420.0 141.1	0.0 0.0	204.0 133.3(6)	512.0 188.2(6)	34.0 11.3	9.1 5.9(6)	7.8 3.6(6)	11.1 2.1
	Min.									
	Max.									
	Avg.									
637	7	5.8	165.0 41.8	12.0 48.0 30.8(6)	96.0 52.7(6)	20.0 7.3(6)	3.0 1.1	0.5 0.2(6)	2.4 1.5(6)	160.0 33.4
	Min.									
	Max.									
	Avg.									
638	7	4.3	125.0 35.1	8.0 4.0(6)	160.0 97.3(6)	106.0 66.2(6)	1.0 0.3	1.4 1.0(6)	3.8 1.0(6)	40.0 9.2(6)
	Min.									
	Max.									
	Avg.									
639	6	5.8	205.0 36.2	12.0 38.0 23.6(5)	100.0 95.2(5)	140.0 80.4(5)	2.5 1.1	0.2 0.2(5)	3.8 1.6(5)	540.0 186.8
	Min.									
	Max.									
	Avg.									

*(6) Indicates the number of samples used in averages when other than the maximum.

Table 25 - Water Quality Data, Cumberland River Basin (cont'd)

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Manganese (mg/l)	Aluminum (mg/l)	Flow (cfs)
640	Min.	6.2		1.0						
	Max.		132.0	26.0	72.0	140.0	6.9	1.4	12.1	17.0
	Avg.		43.7(4)*	13.6	61.0(4)	67.0(4)	3.0	0.6(4)	6.8(4)	9.6
641	Min.	6.5		10.0						
	Max.		64.0	28.0	68.0	160.0	1.8	0.5	2.4	13.0
	Avg.		19.5	20.0(5)	44.0(5)	43.0(5)	1.0	0.2(5)	1.7(5)	3.6
642	Min.	5.5		12.0						
	Max.		180.0	21.0	64.0	146.0	1.5	0.2	2.8	5.4
	Avg.		38.4	15.7(4)	43.0(4)	43.2(4)	0.9	0.1(4)	1.3(4)	1.6(4)
643	Min.	4.3		0.0						
	Max.		268.0	24.0	152.0	322.0	1.8	1.3	7.3	1030.0
	Avg.		47.6	11.3(6)	112.0(6)	104.7(6)	0.6	0.6(6)	2.6(6)	242.6
644	Min.	6.0		92.0						
	Max.		9.0	122.0	144.0	140.0	0.8	0.2	2.9	20.0
	Avg.		4.3	111.5(4)	132.0(5)	31.4(5)	0.5(5)	0.1(5)	1.6(4)	5.3
645	Min.	6.1		82.0						
	Max.		4.0	128.0	144.0	170.0	1.0	0.2	2.5	42.0
	Avg.		1.3	107.4(5)	128.4(5)	61.0	0.4	0.1(5)	1.3(5)	21.0
646	Min.	2.5		0.0						
	Max.		1570.0		500.0	1300.0	77.0	10.5	69.0	12.3
	Avg.		786.1		365.5(6)	765.3(6)	52.0(6)	6.6(5)	39.4(5)	2.7
647	Min.	2.4		0.0						
	Max.		1920.0	0.0	400.0	1200.0	172.0	9.0	68.0	35.0
	Avg.		974.6	0.0	260.7(6)	768.0(6)	99.8	6.4(6)	48.2(6)	6.2
648	Min.	2.7		0.0						
	Max.		1400.0		320.0	1210.0	149.0	8.7	56.0	103.0
	Avg.		740.0		251.0	574.7	72.7	6.0	31.0	45.6(5)
649	Min.	3.2		0.0						
	Max.		144.0		100.0	95.0	7.4	1.0	3.5	100.0
	Avg.		96.8		49.2	46.0	3.5	0.4	2.3(4)	37.1

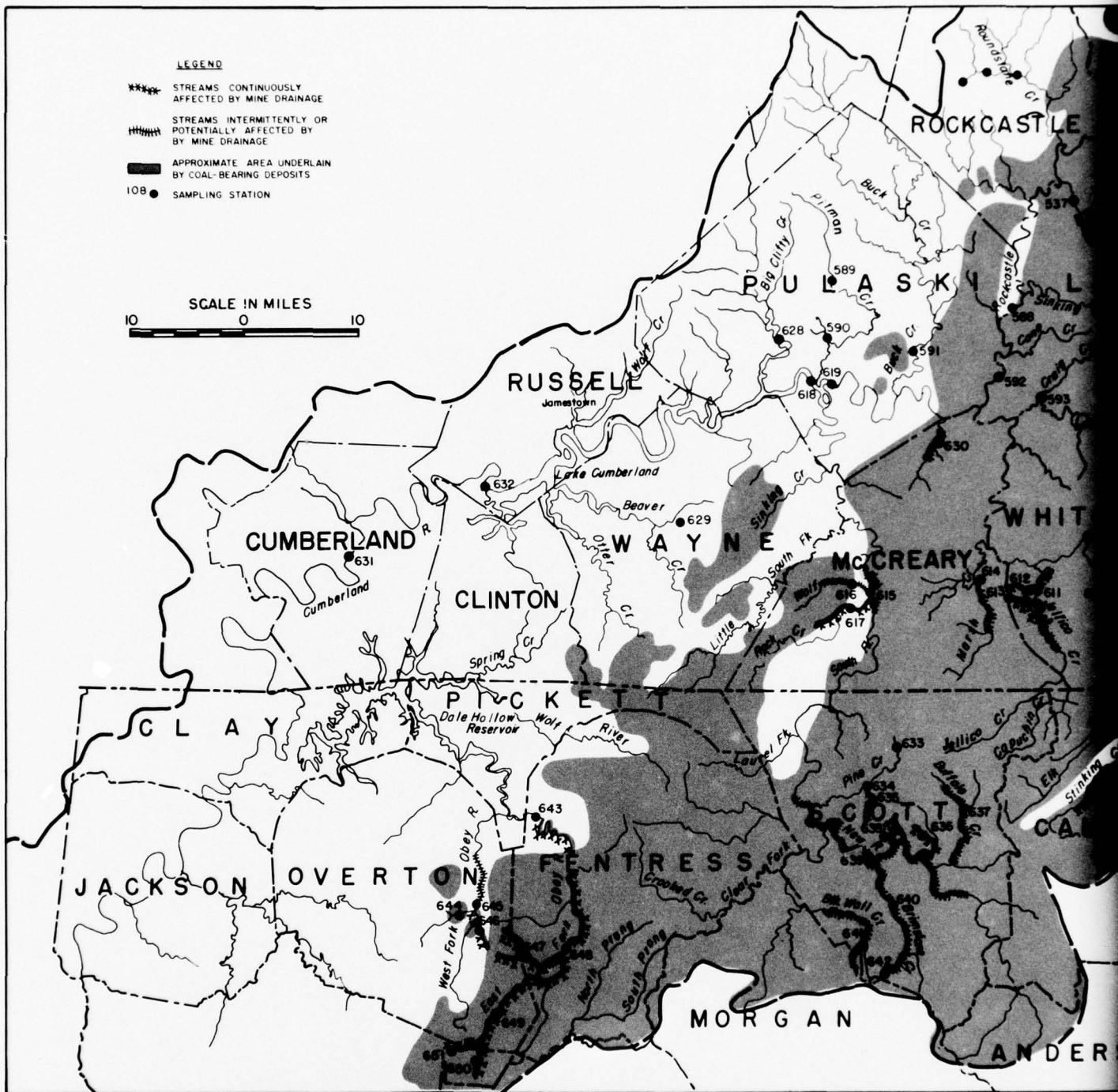
*(4) Indicates the number of samples used in averages when other than the maximum.

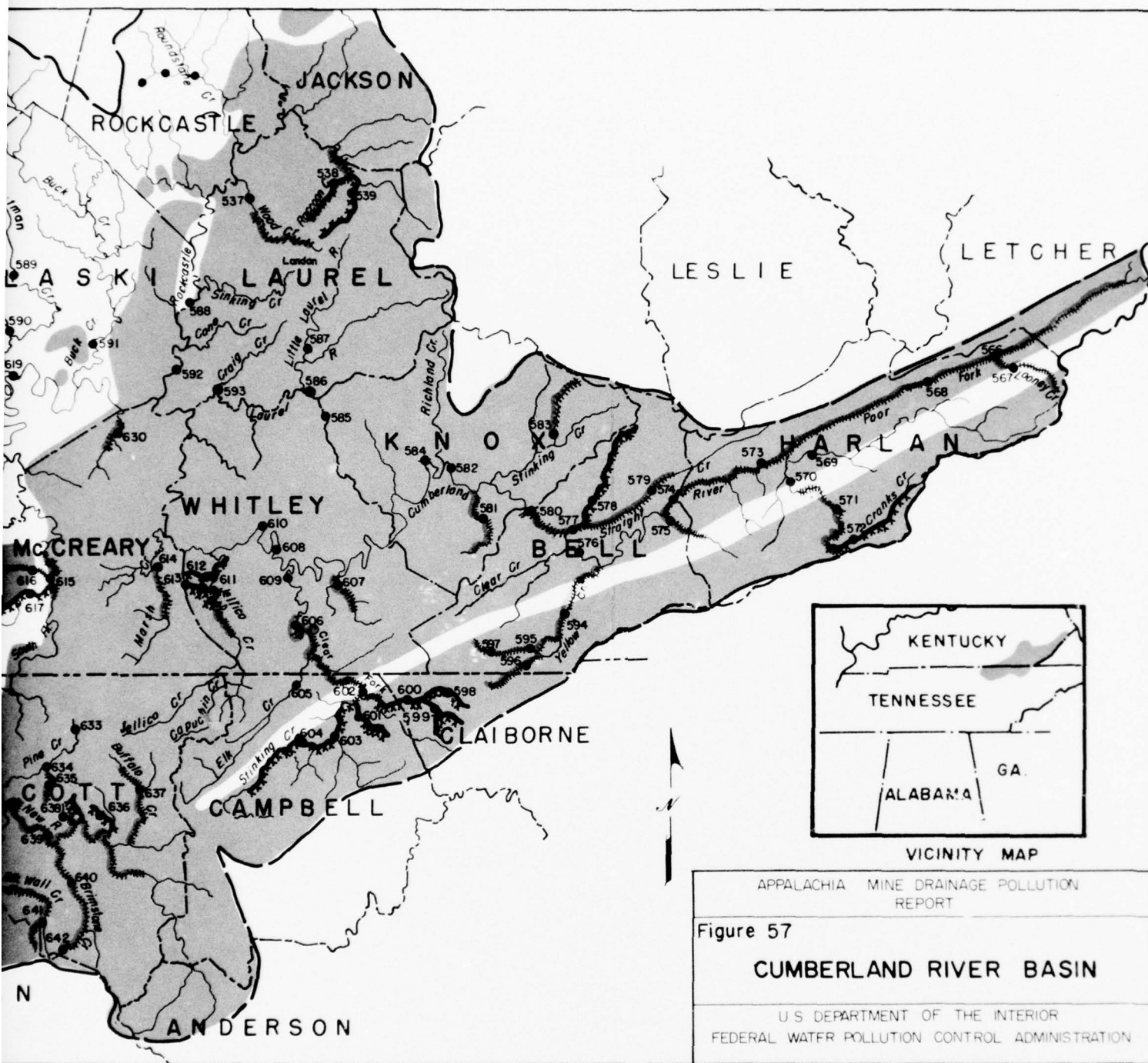
Table 25 - Water Quality Data, Cumberland River Basin (cont'd)

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Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Manganese (mg/l)	Aluminum (mg/l)	Flow (cfs)
650	5	3.3	156.0 68.0	0.0 8.0 2.6	230.0 79.0	195.0 55.5	12.3 5.6(4)*	1.6 0.6(4)	3.8 2.1(4)	30.0 11.4
651	4	2.3	7200.00 3677.0	0.0	420.0 290.0	5500.0 2420.0	1700.0 750.0	6.7 3.8	78.0 70.2	2.1 0.9(3)
652	1	7.2	7.0	100.0	124.0	22.0	0.8	-	-	-
653	1	7.2	0.0	119.0	152.0	16.0	2.0	-	-	-
654	1	7.0	0.0	105.0	112.0	10.0	29.0	-	-	-
655	1	6.9	0.0	110.0	128.0	10.0	0.2	-	-	-
656	1	6.3	0.0	111.0	124.0	11.0	0.2	-	-	116.0
657	1	7.1	0.0	93.0	108.0	4.0	0.4	-	-	-
658	1	7.4	0.0	94.0	96.0	3.0	0.2	-	-	-
659	1	7.2	0.0	120.0	128.0	16.0	0.5	-	-	-
660	1	6.8	0.0	95.0	104.0	110.0	0.2	-	-	306.0

*(4) Indicates the number of samples used in averages when other than the maximum.





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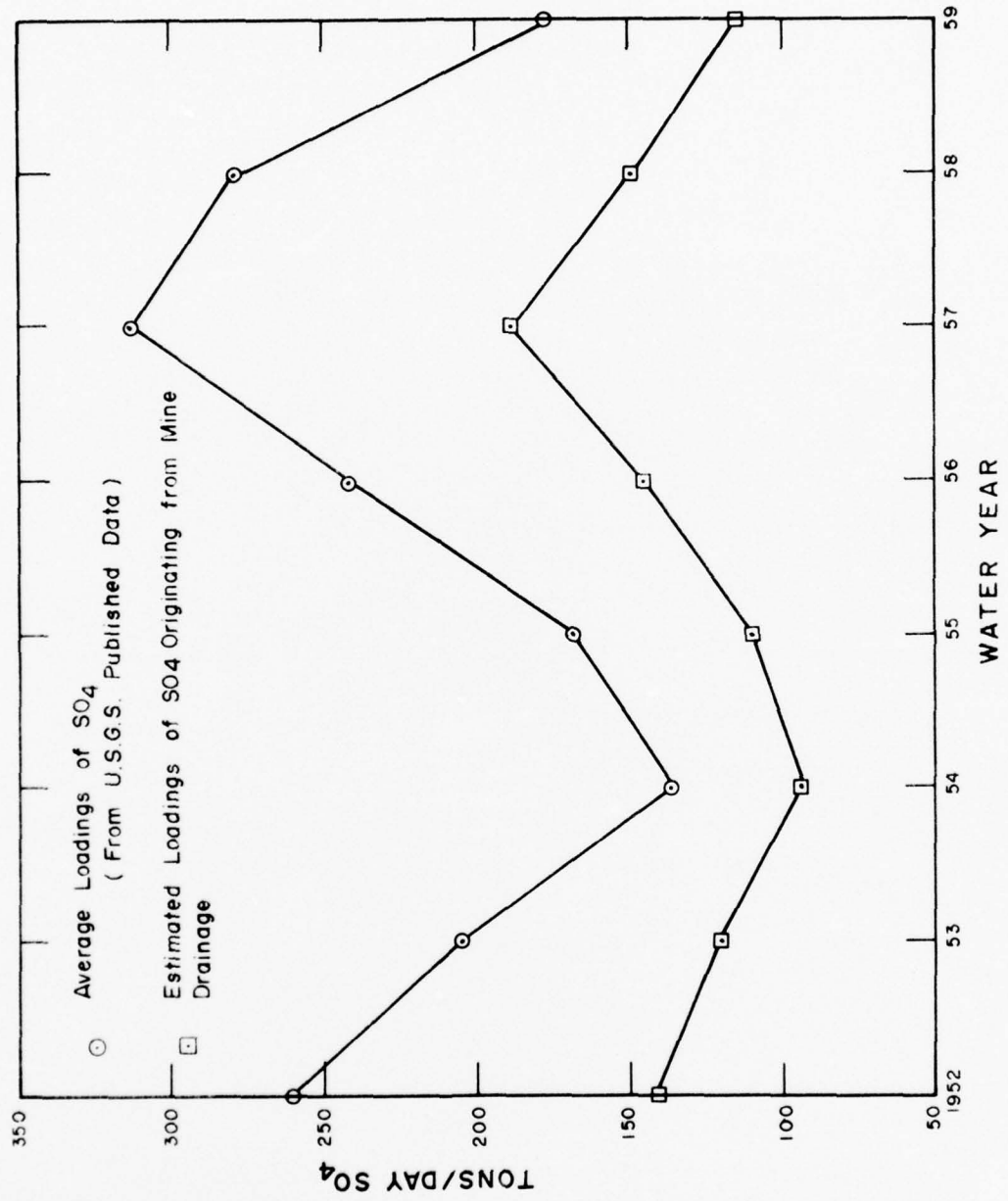


Figure 58. Average loads of total sulfate and sulfate considered to originate from coal mine drainage carried by the Cumberland River at Williamsburg, Kentucky.

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Tennessee and Black Warrior River Basins

Description

The Tennessee River is formed by the Holston and French Broad Rivers which join just above Knoxville, Tennessee. From this point, the Tennessee River, flows 650 miles through Tennessee, Alabama, and Mississippi to its confluence with the Ohio River. The Tennessee River basin has a total drainage area of 40,900 square miles, about 23,000 square miles of which is within Appalachia.

Physiographic features differ significantly within the Tennessee basin, ranging from the mountainous Blue Ridge physiographic region on the east to the flat-lying Coastal Plain region on the west. Coal reserves lie mainly within the Appalachian Plateaus region, which is underlain by nearly flat-lying sandstones, shales and coals of Pennsylvanian and Mississippian age.

The coal reserves of Tennessee are contained in Pottsville series rocks of Lower Pennsylvanian age. Pennsylvanian rocks in Tennessee consist almost entirely of sandstone, shale and conglomerate, with coal beds and thin limestones comprising a small percentage of the total. Twenty-two Tennessee counties contain coal reserves, fifteen of which are wholly or in part in the Tennessee River basin (Fig. 1). The total recoverable coal reserve in Tennessee is estimated to be about 1 billion tons (Luther, 1959). Commercial coal mining began in Tennessee in the 1830's. Peak production was reached in 1956, when 9 million tons were mined.

Some coal mining is done in the upper portion of the Black Warrior River basin, which lies immediately to the south of the Tennessee watershed in northern Alabama.

The Warrior, Cahaba, Coosa, and Plateau coal fields of northern Alabama contain large reserves of bituminous coal in beds of the Pottsville Formation of Pennsylvanian age. (Culbertson, 1964). Total minable coal reserve in these fields is estimated to be about 13.7 billion tons. Counties with important coal reserves are Jefferson, Tuscaloosa, Walker, Bibb, Shelby, and St. Clair. Jefferson, Tuscaloosa, and Walker Counties together contain 77 percent of the total reserves. Coal has been commercially mined in Alabama since 1832. Peak production was 21.5 million tons in 1926. Most of the production has been from Jefferson and Walker Counties, and it is these Counties in which mine drainage pollution occurs.

Mine Drainage Sources and Their Effect on Stream Quality

Mine drainage causes pollution of streams in the upper Tennessee River and Black Warrior River basins, but the problem is small in magnitude in this area as compared to some other Appalachian Region basins.

Surface mining of coal has left 18,600 acres of disturbed unreclaimed land in the Tennessee and Black Warrior basins. The number of underground and surface mine drainage sources is not known.

Stream quality data indicate that more than 20 tons/day of unneutralized mine drainage acidity is carried by streams in the area. However, this acidity is rapidly neutralized by natural sources of alkalinity and pollution effects are, therefore, not generally observable very far from the source. It is estimated that at least 150 miles of streams are significantly polluted by mine drainage, most of them only periodically. Streams found to be significantly polluted are listed in Table 26 and their locations are shown in Figures 59, 60, and 61. Data in Table 27 show the quality of these streams at the time of study. In addition to the streams that are presently known to be polluted, streams where mine drainage pollution may be significant are shown in Figures 60, 61, and 62.

Table 26 - Streams in the Upper Tennessee River Basin
Found to be Significantly Polluted by Mine Drainage

<u>Map Station Number</u>	<u>Stream</u>	<u>County</u>
1	Big Creek	Tazewell, Va.
2	Coal Creek	Tazewell, Va.
10	Russell Creek	Wise, Va.
11, 17	Guest River	Wise, Va.
	Powell River	Wise, Va.
18	Glade Creek	Wise, Va.
	Callahan Creek	Wise, Va.
27, 28	Jones Creek	Lee, Va.
29	Reeds Creek	Lee, Va.
	N. Fork Powell River	Lee, Va.
31	Big Creek	Anderson, Tenn.
32	Cove Creek	Anderson, Tenn.
38	Indian Creek	Morgan, Tenn.
40	Little Emory River	Morgan, Tenn.
41	Crooked Fork	Morgan, Tenn.
42	Emory River	Morgan, Tenn.
43	Mill Creek	Morgan, Tenn.
51	Rock Creek	Cumberland, Tenn.
52	Big Possum	Cumberland, Tenn.
53	Woodcock Creek	Sequatchie, Tenn.

Chemical evidence of coal mine drainage pollution in streams in the Virginia portion of the Tennessee River basin (Stas. 1-29, Fig. 60) is expressed by reduction in natural alkalinity levels and by above normal concentrations of mine drainage indicators. Generally, only iron and manganese are present in excessive concentrations as mine drainage indicators. High acidity concentrations and low pH values are not observed, because stream alkalinity and the limestone and dolomite beds over which the streams flow rapidly neutralize any acidity that enters the surface waters. Reeds Creek (Sta. 29) was acid when examined and had a pH of 4.2. Pollution of Reeds Creek is caused by extensive surface and underground mining.

In the Tennessee portion of the Tennessee River basin (Stas. 31-55, Figs. 60 and 61), Mill Creek, Big Possum Creek, and Woodcock Creek were found to have pH values below 5.0. No other stream had pH values of less than 6.2 at the time of examination. Other significantly polluted streams, as listed in Table 26, had excessive concentrations of mine drainage indicators and/or the natural alkalinity was depleted by reaction with mine drainage acidity.

The water quality data in Table 27 do not necessarily reflect the severity of mine drainage pollution in some streams. The Tennessee Game and Fish Commission has reported, for example, that Beech Grove Fork (Sta. 34) and Poplar Creek (Sta. 37) are polluted during periods of high runoff, when mine drainage pollutants are flushed into these streams. In addition, what may appear to be minor mine drainage pollution may actually represent conditions that significantly affect the biological life in some streams. The Tennessee Game and Fish Commission reports, for example, that in 1958 Crooked Fork (Sta. 41, Fig. 60) was an ideal muskellunge habitat, but that it is no longer suitable for this purpose due to recent surface mining operations. The chemical analyses in Table 27 for this stream show a depletion in alkalinity and slightly high concentrations of other indicators, but no evidence of severe pollution at the time of sampling.

Through a biological examination of streams in Jefferson and Walker Counties, Alabama, in the Black Warrior River basin (McClellan and Zoellner, 1966), it has been determined that Lost Creek, Mill Creek and Cane Creek (Fig. 62) are likely to be polluted by mine drainage. The Alabama Geological Survey (written communication) has reported that the Black Branch, Spring Creek, Cane Creek, Shelton Branch, Hanna Mill, Daniel Creek and tributaries to Short Creek, Spring Creek, and Black Branch in the Black Warrior River basin (Fig. 62), were found to have pH values ranging from 3.5 to 4.5. Mine drainage pollution in this area is from active or inactive surface mines. Luxapallila Creek is also reportedly polluted by mine drainage (U. S. Dept. of Agriculture, 1966).

Table 27 - Water Quality Data, Tennessee River Basin

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Manganese (mg/l)	Specific Conductance (Micro-mho)	Flow (cfs)
1	2	6.6	10.0 6.0	11.0 9.5	44.0 44.0	13.0 14.5	0.9 0.9	0.2 0.1	115.0 112.5	21.1 16.0
2	2	7.0	4.0 2.0	31.0 30.5	88.0 84.0	31.0 29.5	2.4 2.0	0.4 0.4	231.0 216.5	8.7 6.4
4	1	7.6	0.0	88.0	120.0	3.0	0.2	0.0	225.0	279
6	2	7.5	0 0	116.0 108.0	144.0 134.0	4.0 4.0	0.4 0.3	0.05 0.025	247.0 240.5	890.0 660.0
10	2	6.9	4.0 2.0	32.0 30.0	152.0 134.0	59.0 56.0	2.6 2.4	0.8 0.6	367 316.5	6.7 6.4
11	2	6.7	2.0 1.0	30.0 23.0	64.0 58.0	22.0 19.0	4.4 2.9	0.4 0.3	171.0 154.5	295.0 248.5
17	2	6.5	8.0 4.0	12.0 11.0	68.0 56.0	18.0 18.0	1.8 1.5	0.4 0.4	154.0 140.5	54.7 41.1
18	2	6.3	6.0 3.5	14.0 12.0	68.0 64.0	28.0 25.0	0.9 0.85	0.8 0.7	152.0 150.0	
26	2	6.4	6.0 4.0	8.0 8.0	44.0 32.0	6.0 4.5	0.4 0.4	0.1 0.05	58.0 49.5	44.8 43.3
27	1	5.1	6.0	1.0	32.0	16.0	1.7	0.2	95	15.2

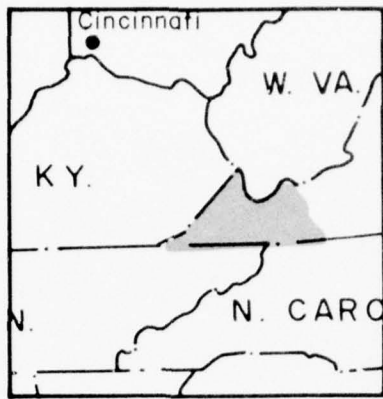
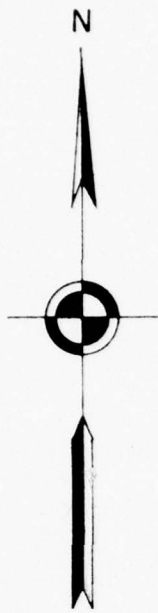
Table 27 - Water Quality Data, Tennessee River Basin (cont'd)

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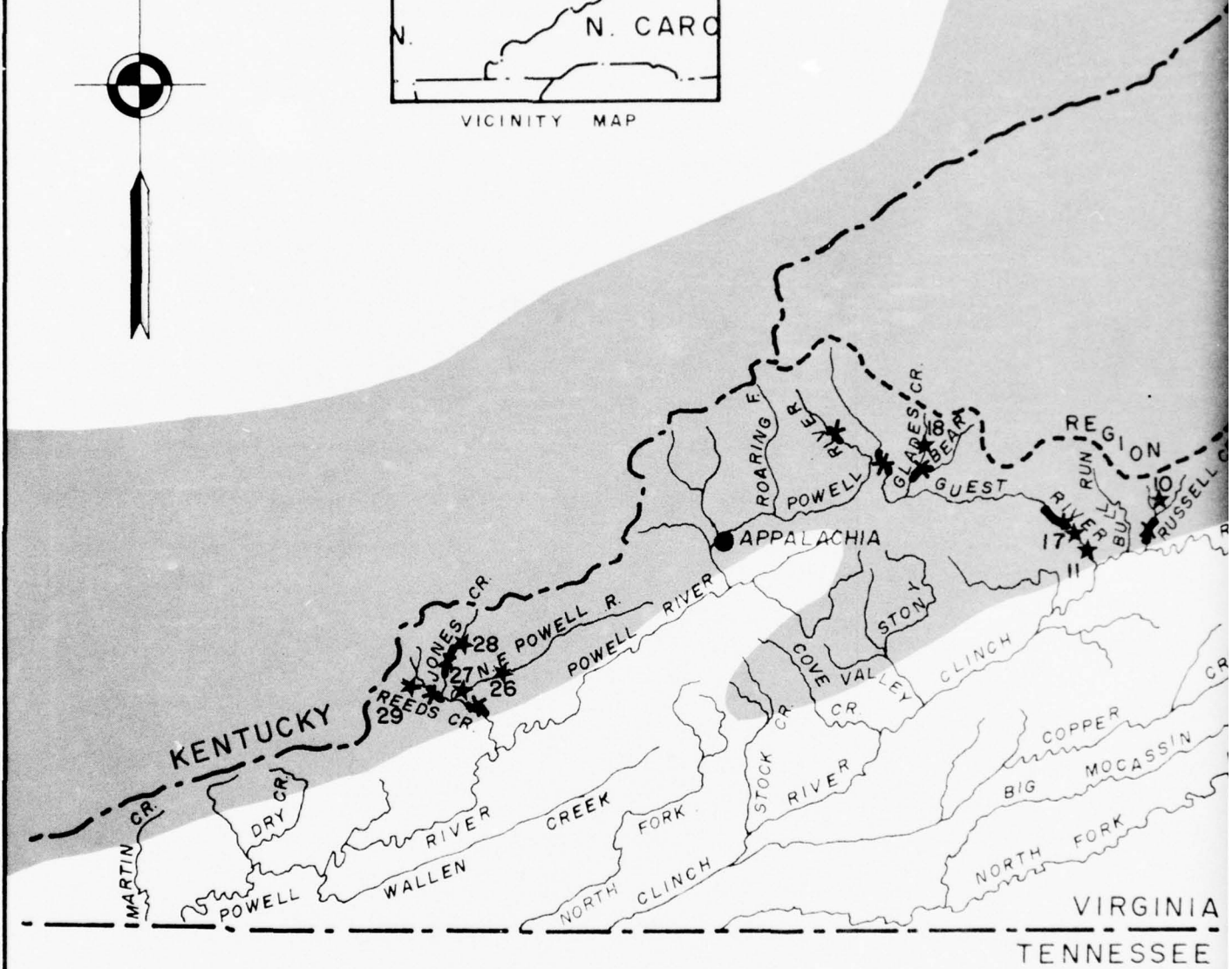
Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Manganese (mg/l)	Specific Conductance(cfs)	Flow
	Min.	6.7								
28	2		8.0	12.0	80.0	14.0	0.5	0.1	98.0	7.1
	Max.		5.0	10.0	54.0	12.0	0.4	0.1	86.0	6.8
	Avg.									
29	1	4.2	17.0	0.0	40.0	31.0	3.5	0.4	144.0	-
	Min.									
	Max.									
	Avg.									
31	2	6.7	8	12	84.0	16	1.3	0.3	137.0	8.8
	Min.		4	10	60.0	13	0.9	0.3	120.5	8.4
	Max.									
	Avg.									
32	1	6.9	6.0	20.0	88.0	1.3	0.6	0.1	120.0	36.5
	Min.									
	Max.									
	Avg.									
34	2	7.0	0.0	32.0	120.0	38	2.2	0.3	217.0	8.3
	Min.		0.0	24.0	74.0	22	1.3	0.25	144.0	6.7
	Max.									
	Avg.									
36	1	7.4	0	64.0	112.0	65	0.4	0.1	331.0	4.9
	Min.									
	Max.									
	Avg.									
37	2	6.9	0.0	46.0	164.0	75.0	1.1	0.5	313	70
	Min.		0.0	35.0	128.0	46.5	.9	0.45	252	40.2
	Max.									
	Avg.									
38	2	6.6	2.0	24	124.0	65.0	0.8	1.7	274.0	8.4
	Min.		1.0	21	80.0	37.0	0.7	0.9	193.0	6.7
	Max.									
	Avg.									
40	2	6.7	2.0	16.0	88.0	43.0	0.4	0.5	202.0	36.2
	Min.		1.0	12.0	64.0	26.0	0.35	0.35	142.5	-
	Max.									
	Avg.									
41	2	6.2	4.0	4.0	80.0	41.0	0.9	0.8	186.0	
	Min.		4.0	4.0	56.0	33.0	0.5	0.7	173.0	
	Max.									
	Avg.									

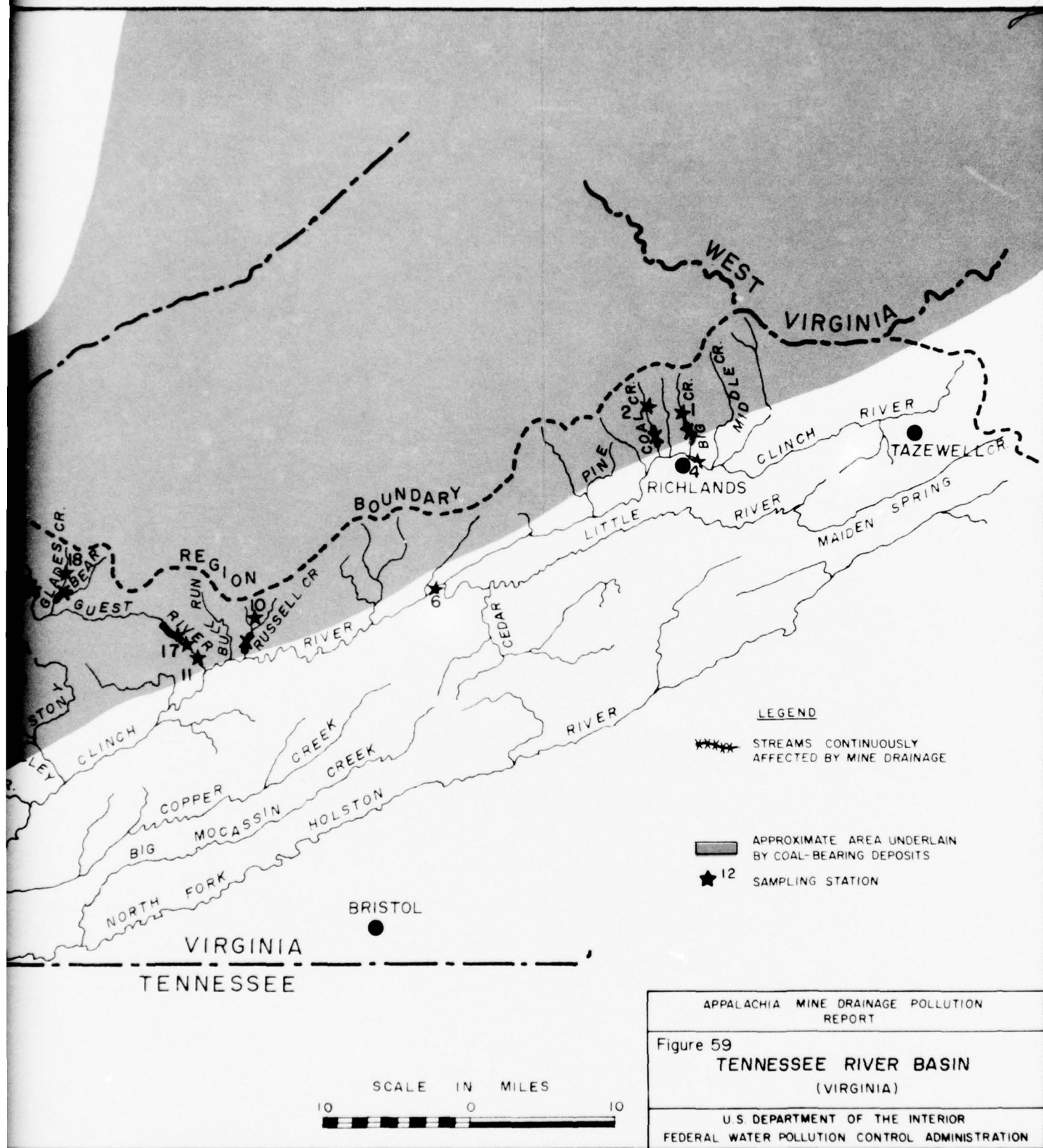
Table 27 - Water Quality Data, Tennessee River Basin (cont'd)

Map Station No.	No. of Samples	pH	Acidity (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Sulfate (mg/l)	Total Iron (mg/l)	Manganese (mg/l)	Specific Conductance	Flow (cfs)
42	1	6.5	0	8.0	36.0	2.0	0.2	0.1	58.0	1200.0
	Min.									
	Max.									
	Avg.									
43	2	4.9	6	2	64.0	24.0	0.5	1.3	117.0	8.7
	Min.									
	Max.									
	Avg.									
44	1	6.5	2.0	8.0	40.0	1.0	0.3	0.1	44.0	1150.0
	Min.									
	Max.									
	Avg.									
46	2	6.6	3.0	10.0	48.0	16.0	1.9	0.2	46.0	6.7
	Min.									
	Max.									
	Avg.									
51	2	6.2	6.0	6.0	8.0	4.0	0.5	0.1	38.0	420.0
	Min.									
	Max.									
	Avg.									
52	2	4.0	20.0	0.0	24	13.0	2.2	0.7	94.0	193.0
	Min.									
	Max.									
	Avg.									
53	2	4.9	6.0	2.0	20.0	3.0	0.4	0.2	49.0	153.0
	Min.									
	Max.									
	Avg.									
54	1	6.9	0.0	24.0	36.0	3.0	0.4	0.1	78.0	7.3
	Min.									
	Max.									
	Avg.									
55	2	6.3	4.0	14.0	40.0	7.0	0.4	0.2	87.0	30.4
	Min.									
	Max.									
	Avg.									
56	2	7.1	0	36.0	76.0	7.0	0.4	0.1	156	272.0
	Min.									
	Max.									
	Avg.									



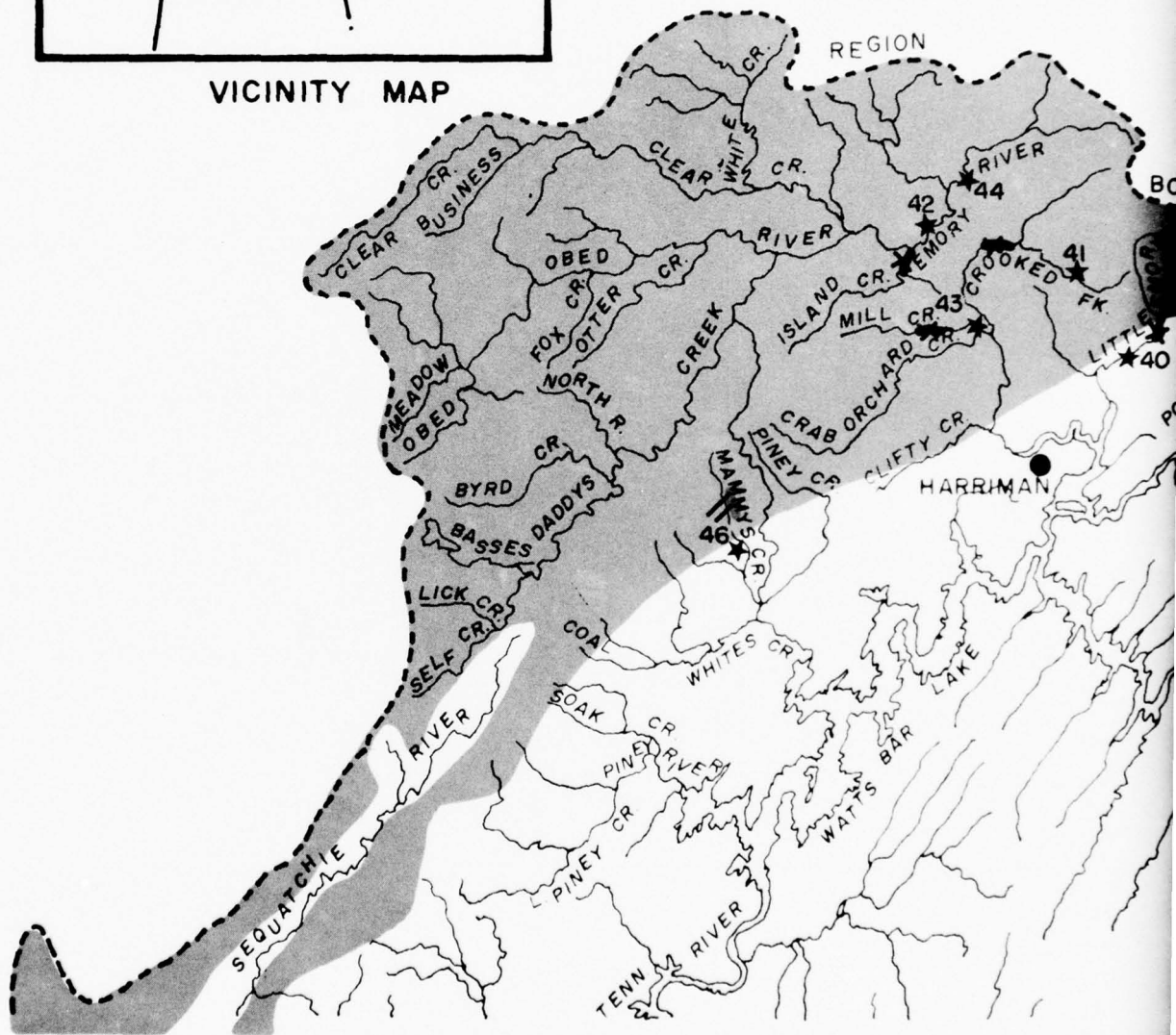
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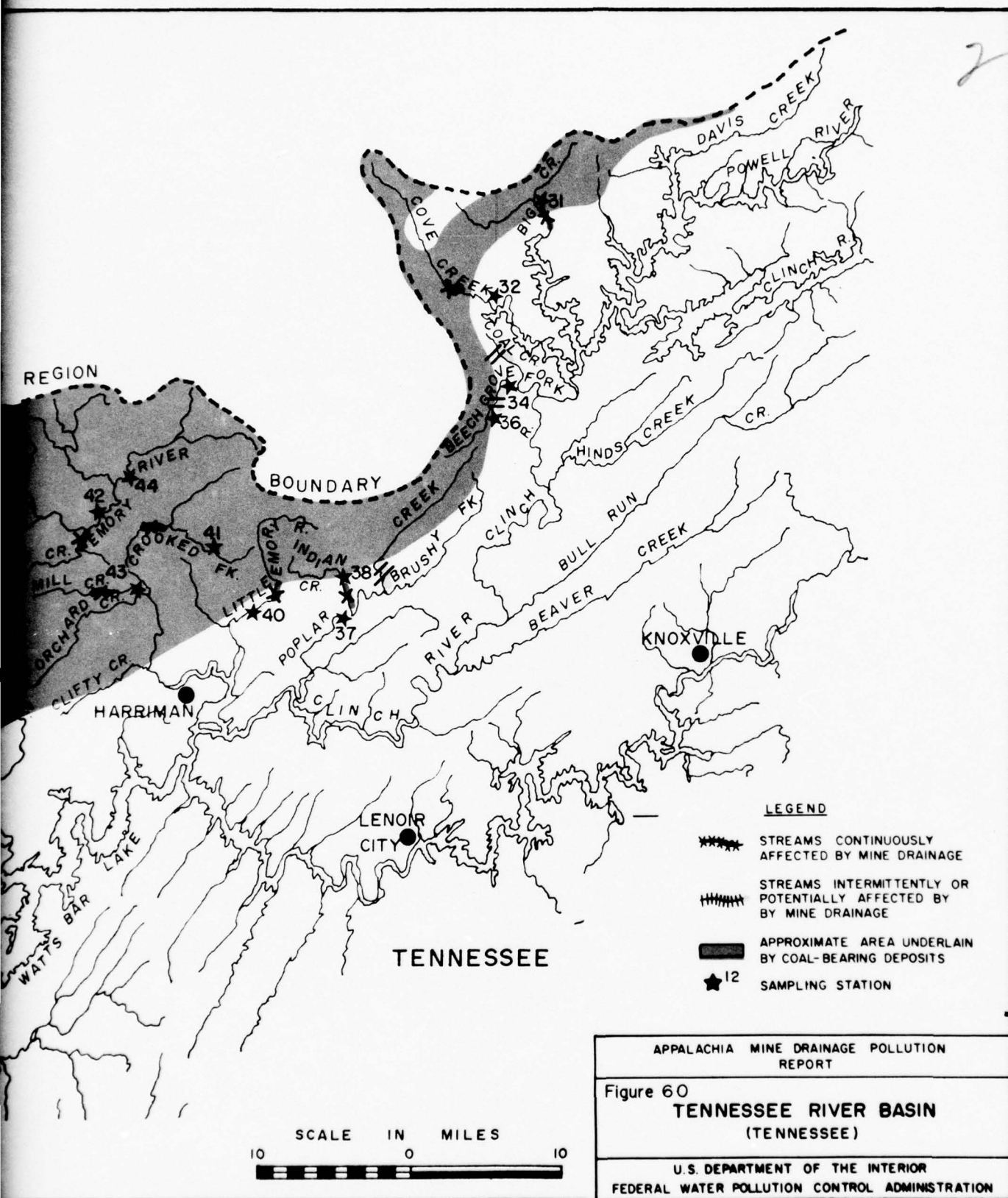




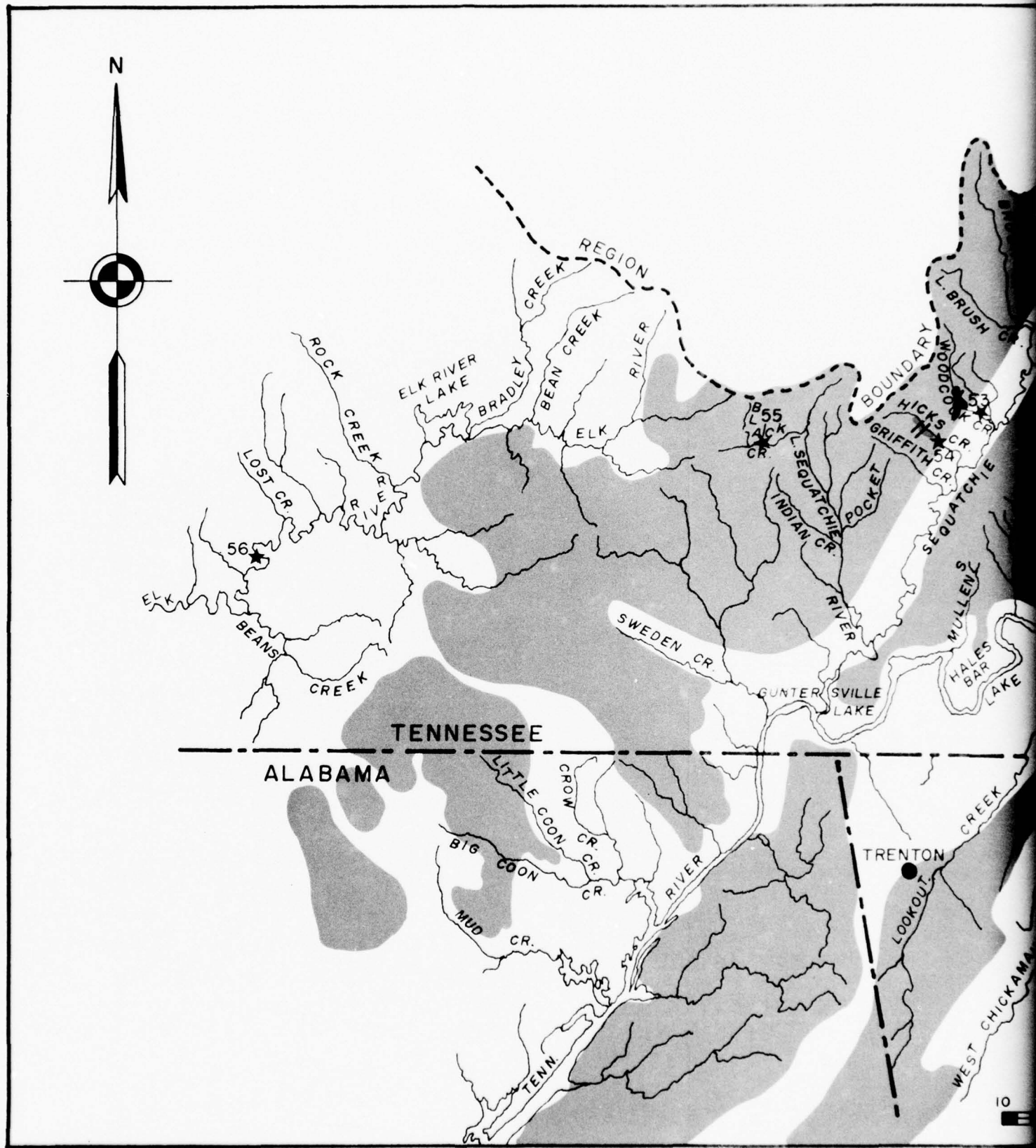


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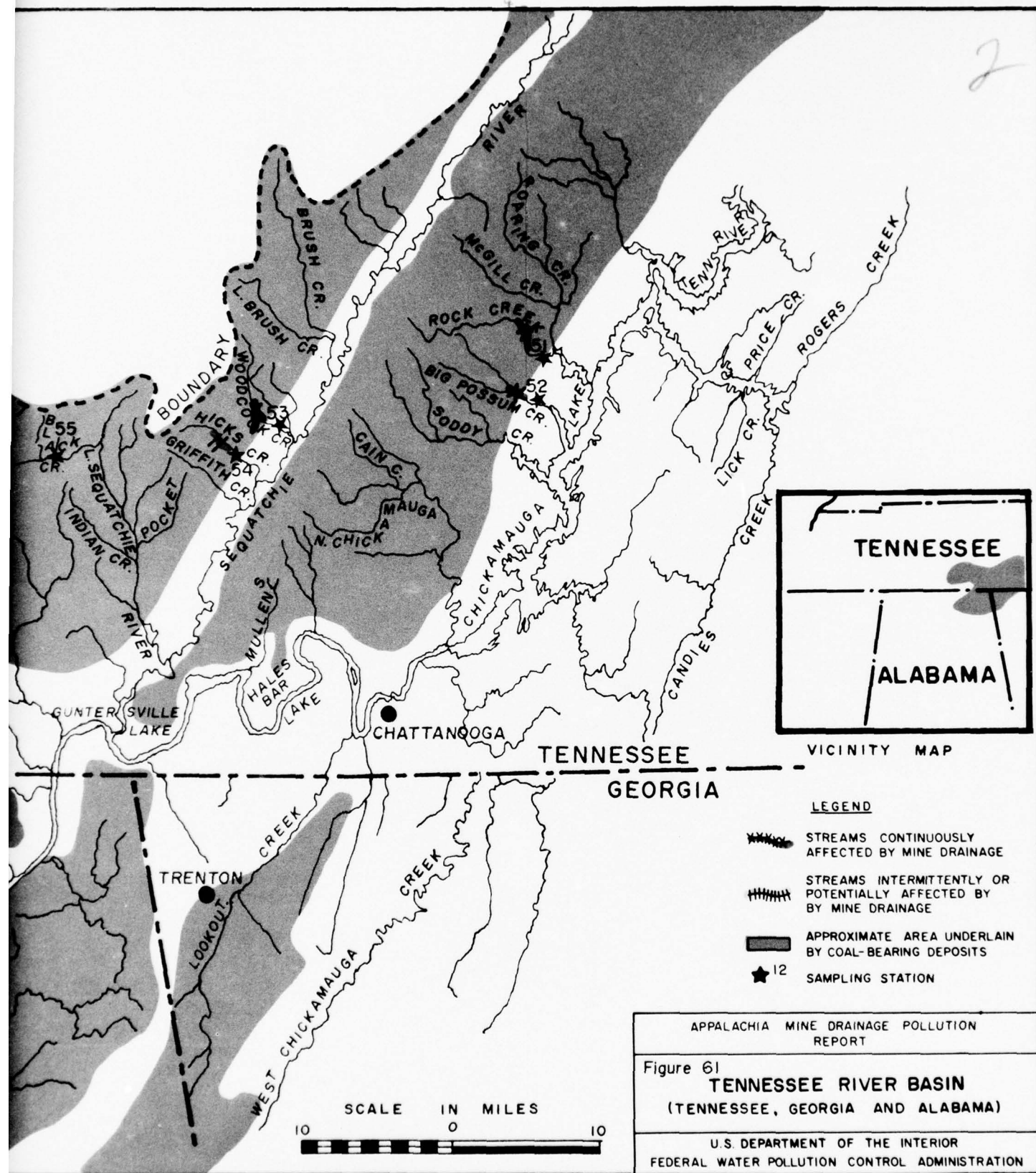




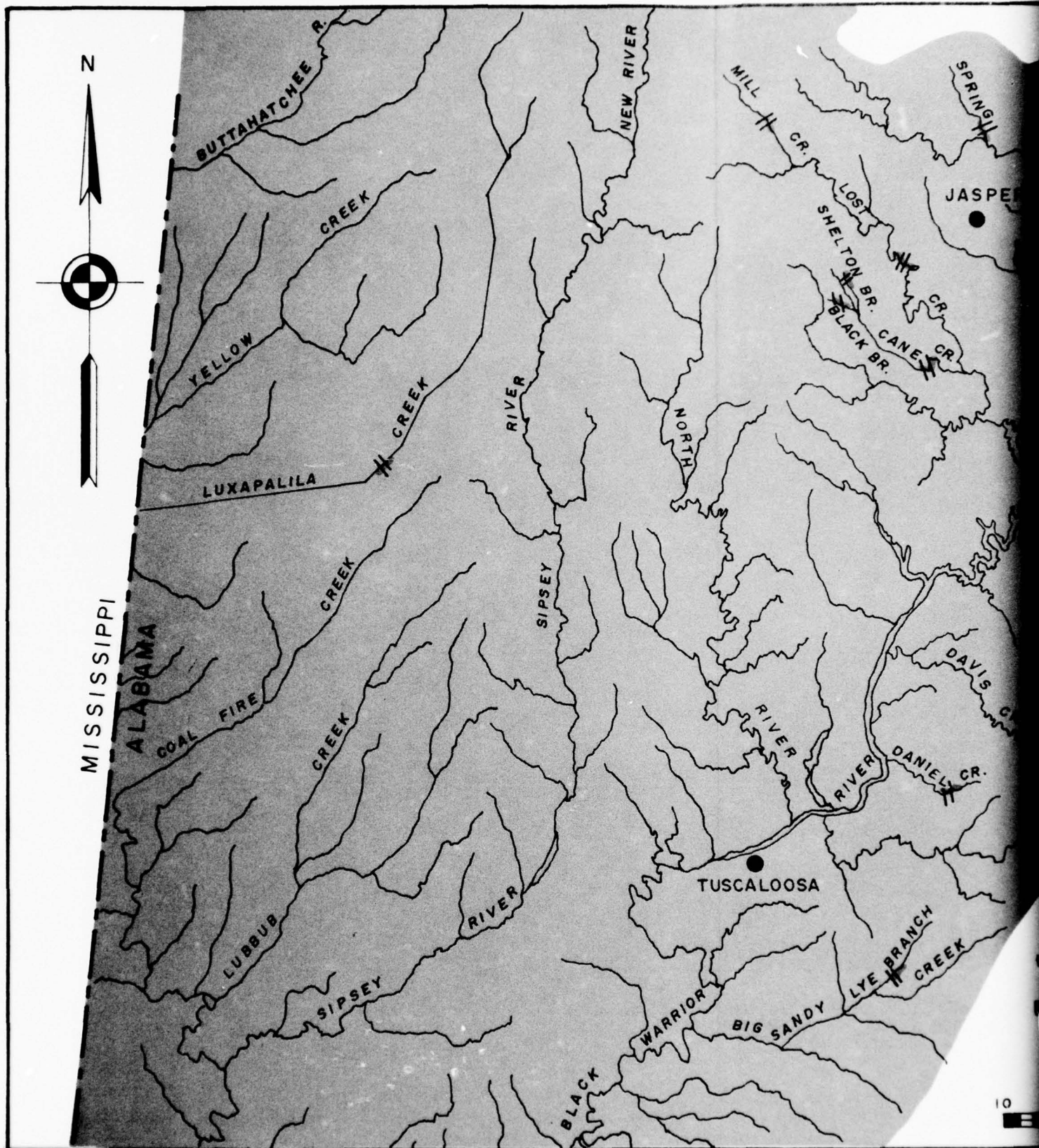
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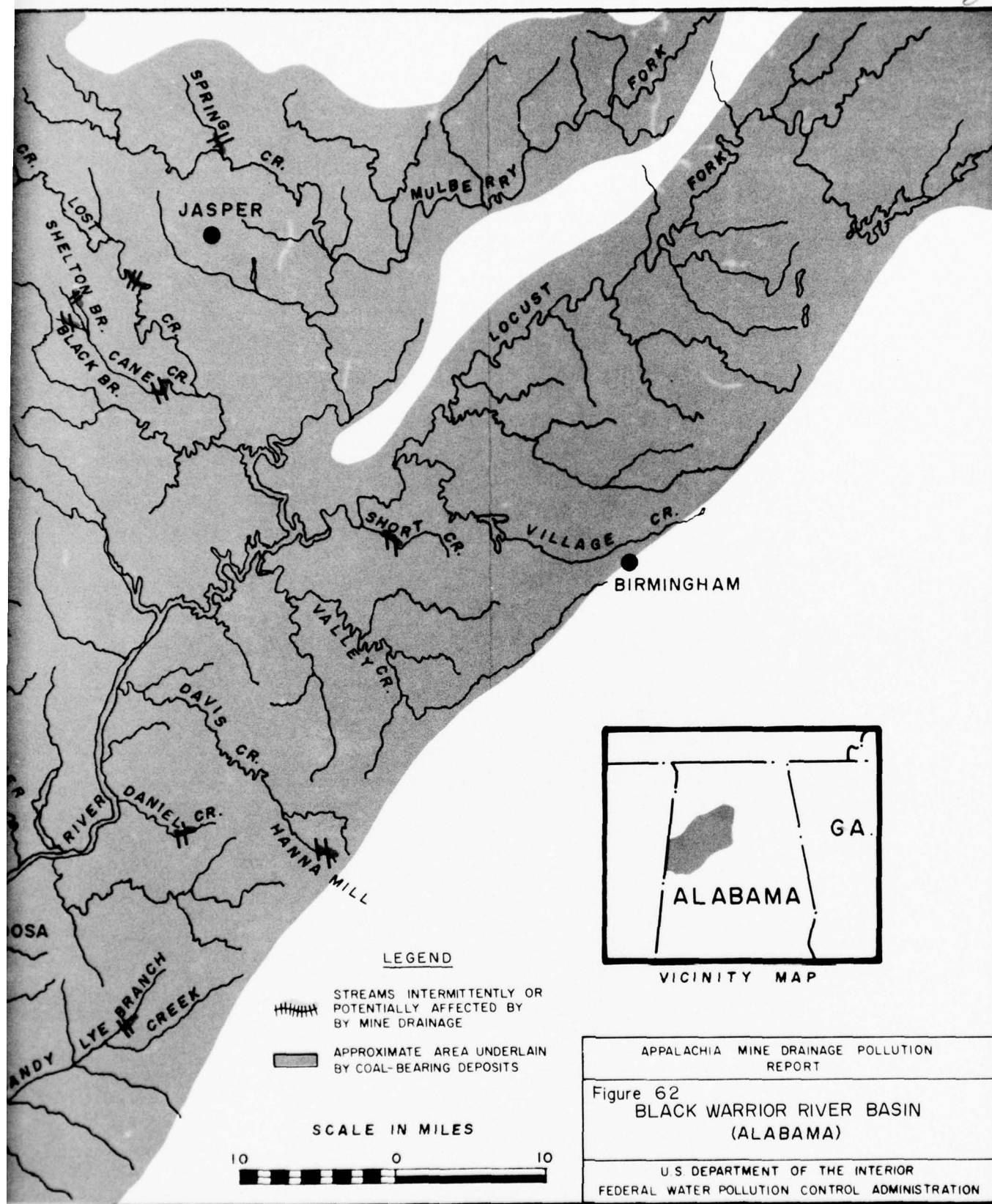


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PROJECTED CONDITIONS

The present problem of mine drainage pollution in Appalachia can be discussed in terms of various parameters such as miles of polluted streams, concentrations of mine drainage indicators in the waters at selected points on streams, or loads of mine drainage indicators carried by streams at selected points. The same parameters could be used to compare the future situation with that of today, but only a few measurements appear useful for comparing conditions in the past with those of today.

Acidity concentrations or loads have generally been used to characterize the problem and, for example, it is estimated in this report that at least 6,000 tons/day of unneutralized acidity enters streams in Appalachia. Acidity is, however, a somewhat difficult and unreliable indicator to use in many cases for several reasons. Three such reasons are, first, that different laboratory methods are used that may give greatly different results, second, that there is no way of adjusting such results to make them comparable, and third, that acidity is often not measurable very far from where it enters a stream, because it is neutralized by natural sources of alkalinity.

For the above reasons analyses were made of average sulfate loads at locations on major streams as listed in Table 28.

The total sulfate loads shown in the figures listed in Table 28 were computed by water year as time and discharge weighed daily averages. Data were obtained from the U. S. Geological Survey Water Supply Papers entitled "Surface Water Quality in the United States," which have been published annually since 1944.

Table 28 - Listing of Streams for Which Average Yearly Sulfate Loads are Given

<u>Stream</u>	<u>Figure Number</u>	<u>Page</u>
1. Susquehanna River at Danville, Pa.	5	51
2. Schuylkill River at Berne, Pa.	4	50
3. Lehigh River at Catasauqua, Pa.	3	49
4. West Branch Susquehanna River at Lock Haven, Pa.	26	95
5. Allegheny River at Kittanning, Pa.	38	133
6. Kiskiminetas River at Vandergrift, Pa.	39	134
7. Monongahela River at Charleroi	41	151

Table 28 (cont'd)

<u>Stream</u>	<u>Figure Number</u>	<u>Page</u>
8. Youghiogheny River at Sutersville, Pa.	42	152
9. Hocking River at Athens, Ohio	46	173
10. Big Sandy River at Catlettsburg, Ky.	52	205
11. Cumberland River at Williamsburg, Ky.	58	247

Sulfate was selected as an indicator because:

1. One molecular weight of sulfate is formed for each molecular weight of sulfuric acid. The weight ratio is also nearly identical, being 0.98 tons of sulfate per ton of sulfuric acid.
2. The sulfate does not disappear when the acidity is neutralized.
3. Calcium sulfate, the usual form, is soluble in the concentrations usually encountered.
4. The analysis for sulfate is reliable.
5. Many sulfate analyses are available.

Available acidity loadings are shown in Figures 4, 26, 39, and 41, for comparison with the sulfate data. The trends in acidity loads seem generally to be reflected by trends in sulfate loads.

A problem in using sulfate as an indicator of mine drainage is an interference from industrial wastes that contain sulfates. This problem prevented use of U. S. Geological Survey data from the Beaver River and Kanawha River basins. In addition, sulfate occurs naturally in Appalachian streams. Therefore, in order to indicate the magnitude of sulfate originating from mine drainage, measured sulfate concentrations were reduced by an average of 20 mg/l. An average sulfate concentration of 20 mg/l was determined to be a representative natural level in several streams not affected by mine drainage. Natural concentrations may be lower than 20 mg/l in some streams, but were not observed to be higher than this in Appalachian streams that are unaffected by drainage from coal areas. In general, it was observed that many of the extreme fluctuations shown in the figures listed in Table 28 resulted from hydrologic variations. Years of high precipitation resulted in low average sulfate concentrations, but high stream loads. In dry years, concentrations were high, but loads low. This type of variation could apparently result in load differences of over 50 percent in two succeeding years.

Data in Figure 5 show that between 1250 and 2000 tons/day of sulfate originated from mine drainage in the Susquehanna River basin portion of the Anthracite region during the period 1946 to 1963. The average amount was about 1500 tons/day. Sulfate loads at the end of this 17 year period were not greatly different than at the beginning.

These data may be useful in projecting the pollution potential from mining in the Anthracite region. Anthracite production was at its lowest level during this century in 1962 (17 million tons/year). Coal production for the Susquehanna basin portion of the Anthracite area is projected as being about the same in 1980 as in 1962. Based on these few data, it might be expected that mine drainage pollution loads in the Susquehanna portion of the Anthracite area will remain in the same order of magnitude in 1980 as today, unless abatement measures are applied.

Sulfate loads in the Lehigh River (Fig. 3) remained about the same during 1945-1952. No recent data are available. Sulfate loads in the Schuylkill River (Fig. 4) were relatively high during 1951-1953 but were less at the end of the period 1948-1959 than in the beginning. Annual anthracite production in 1980 is projected to be perhaps half that during the period 1946-1948. Based on this projection, mine drainage pollution loads in 1980 will probably not exceed those shown in Figures 3 and 4, but substantial improvement is not anticipated without an abatement program.

Sulfate loads carried by the West Branch of the Susquehanna at Lock Haven, Pennsylvania (Fig. 26) appear to be an excellent indicator of the amount of mine drainage pollution discharged to this stream during 1946-1963. Variation in loads was not extreme during this period and loads at the end of the period were essentially the same as in the beginning. Coal production during this period has been relatively stable, averaging about 9 million tons/year. Projected production in 1980 is about 8.5 million tons (Wessel, and others, 1964). It can reasonably be concluded on the basis of past and present pollution loads and past, present, and projected mining activity that mine drainage pollution in the West Branch of the Susquehanna River will continue at the present level until 1980 unless abatement measures are applied.

Sulfate load data for the Allegheny River above the Kiskiminetas River are given in Figure 38, and sulfate load data for the Kiskiminetas River are given in Figure 39. Data in both of these figures appear to indicate some trend toward an overall decrease in pollution loads in the Allegheny basin, but the combined load of sulfate attributed to mine drainage in the Allegheny basin was, within the limits of error, the same in 1962 (1,960 tons/day) as in 1947 (1,900 tons/day).

Chemical data are available for the Allegheny River from as far back as about 1910 (U. S. Public Health Service, 1943, p. 1018). Total sulfate loads were, for example, 1915 - 2,000 tons/day, 1920 - 3,100 tons/day, 1930, 2,100 tons/day, 1940 - 3,100 tons/day. The minimum loading since 1915 occurred during 1915 and the maximum was about 4,200 tons/day in 1927. The maximum total sulfate load during 1946-1963 was about 4,500 tons/day in 1951 and the minimum load was about 2,650 tons/day in 1962.

It is not presently known if the fluctuations in mine drainage pollution in the Allegheny basin can be explained, but it is clear that the loads since 1915 have fluctuated in the same general range and it would seem reasonable to expect this to continue in the foreseeable future unless abatement measures are taken.

Clark (1965) showed evidence that the Monongahela River experienced large increases in acidity during the period 1920-1934 then decreased very gradually in acidity up to 1957. Clark's data indicate very little change from 1944 to 1957. Clark's data are confirmed by data in Figure 41, which show that acidity and sulfate loads in the Monongahela River at Charleroi experienced little permanent change during the period 1945-1958.

Clark (1965) also showed that acidity concentrations in the Monongahela River apparently responded somewhat to rates of mining in the river basin. Coal production in the entire Monongahela basin was about 100 million tons in 1945 and about 65 million tons in 1958 and 1965. Projected production for 1980 is about 90 million tons (computed from Little, 1964).

On the basis of past and present water quality and past, present, and projected mining rates, it would be expected that mine drainage pollution in the Monongahela basin will not be greatly different in 1980 than today, unless corrective measures are taken.

Data available for the Big Sandy River basin (Fig. 52) show that little change in the loads of sulfate originating from mine drainage pollution occurred between 1957 and 1963. Coal production in 1980 is expected to be about 85 million tons as compared to 65 million tons in 1965 (computed from Little, 1964). Mine drainage pollution would not be expected to be substantially different in 1980 than it is today based on past water quality and projected increases in coal mining rates. A maximum increase of about 20 percent in pollution loads would be projected if loads responded directly to mining activity.

The total mine drainage pollution load in the Hocking River as indicated by sulfate loads (Fig. 46) is not great in comparison to some other drainage basins, but it is large in view of the amount of coal extracted (1.6 million tons in 1965). Data in Figure 46 indicate an increase in sulfate loads of about 50 percent between 1955 and 1965. Coal production of about 10 million tons per year is projected for 1980 (computed from Little, 1964). Such a large increase in mining activity could lead to substantially increased mine drainage pollution loads in the Hocking basin, if corrective measures are not applied.

The previous discussion of seven of the sub-areas included in this report indicates that while fluctuations have occurred in mine drainage pollution loads, no substantial permanent increases or decreases in loads appear to have occurred in recent years. An exception to this generalization may be the Hocking basin, where there is a possible trend toward increasing pollution loads. On the basis of the data from the seven sub-areas, which discharge about two-thirds of the mine drainage acidity formed in Appalachia, it is believed that the total quantity of mine drainage pollutants discharged to streams in Appalachia will remain in the same order of magnitude in 1980 as today unless corrective measures are applied.

Although the quantity of pollutants discharged to streams may remain in the same order of magnitude between now and 1980, it is expected that the mine drainage pollution problem will become more severe in terms of the number of inactive mines contributing pollution. In addition, unless controls are exercised, previously unpolluted streams will be degraded as mining advances into new areas.

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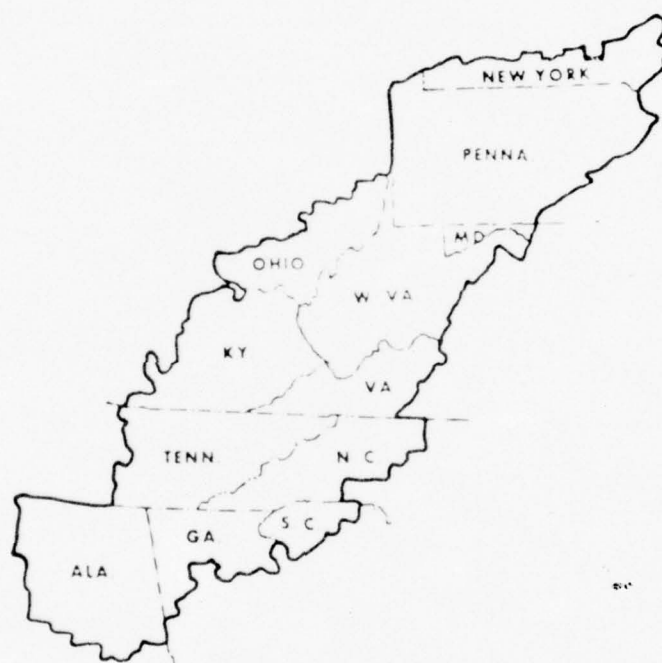
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A REVIEW OF CURRENT RESEARCH
ON COAL MINE DRAINAGE
IN APPALACHIA

DEVELOPMENT OF WATER
RESOURCES IN APPALACHIA



UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

AREA I MINERAL RESOURCE OFFICE
Pittsburgh, Pennsylvania

1967

APPENDIX C ATTACHMENT B

A REVIEW OF CURRENT RESEARCH
ON COAL MINE DRAINAGE
IN APPALACHIA

By Robert W. Stephan and Walter C. Lorenz

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
Area I Mineral Resource Office
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1967

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A REVIEW OF CURRENT RESEARCH
ON COAL MINE DRAINAGE
IN APPALACHIA

by

Robert W. Stephan^{1/} and Walter C. Lorenz^{1/}

ABSTRACT

The purpose of this report is to present the status of current research on methods for the abatement or control of acid mine drainage. Research and process technology is being investigated by Federal and State agencies, universities, and private industry. A literature review of the current research is presented in the form of an annotated bibliography.

INTRODUCTION

A literature review of current research on coal mine drainage pollution has been made at the request of the Office of Appalachian Studies, Corps of Engineers, U. S. Army, Cincinnati, Ohio. The water in more than 5,000 miles of streams and 13,000 acres of ponds^{2/} in Appalachia has been polluted by coal mine drainage. About 72 percent of the bituminous coal and 95 percent of the anthracite produced in the United States in 1964 was mined in the Appalachian States of Alabama, Georgia, Kentucky, Maryland, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia.^{3/}

The purpose and objective of this report is the investigation and evaluation of present day technology for the control of acid mine drainage.

This report is the first of a series of reports by the Bureau of Mines on the coal mine drainage problem for the Office of Appalachian Studies, Corps of Engineers.

^{1/} Chemical engineer, Area I Mineral Resource Office, Bureau of Mines, U. S. Department of the Interior, Pittsburgh, Pa.

^{2/} Kinney, Edward C. Extent of Acid Mine Pollution in the United States Affecting Fish and Wildlife. U. S. Department of the Interior, Bureau of Sport Fisheries and Wildlife, Circ. 191, 1964, 27 pp.

^{3/} Bureau of Mines. 1964 Minerals Yearbook. v. 2 Mineral Fuels, 1965, 509 pp.

The Acid Mine Drainage Problem

The U.S. Public Health Service estimated in 1962 that approximately 3.2 million tons of sulfuric acid are discharged annually into streams from active and abandoned coal mining operations in the Appalachia Region.^{4/}

The acid and sulfate from acid mine drainage causes rapid deterioration of concrete structures serving as piers, abutments, and concrete-lined channels, and it corrodes steel, thus necessitating special materials of construction in the handling and utilization of acid mine water.

The value of the polluted stream for domestic and industrial water use, as well as for recreational purposes, is drastically reduced. The potential of many communities for industrial- and recreational-site development is degraded by poor water conditions.

Acid mine water is produced in both active and abandoned underground and surface coal mining operations. Abandoned underground mines constitute a unique pollution problem because acid water continues to be formed years after the closing of the mines, without apparent decrease in the acidity. Acid waters also are produced from mine refuse piles and from preparation plants.

SOURCES OF POLLUTION

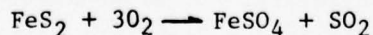
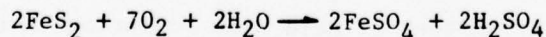
Occurrence of Iron Sulfides

Iron sulfide, commonly known as pyrite, is an intrinsic mineral associated with bituminous coal and anthracite coal, and with the rock strata above and below the coalbeds. Before mining operations, these sulfide-bearing rocks are not exposed to oxidizing agents. Mining operations admit air and water into the mine openings and may also lower the ground water table to the floor of the mine.

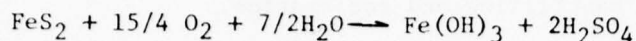
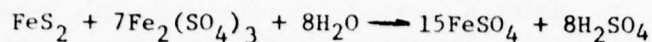
After the coal is mined and the pyritic material becomes exposed to the action of the elements, whether it is an underground mine or a surface mine, the mechanisms of pyrite oxidation are initiated and the formation of acid mine water started.

Oxidation of Iron Sulfides

The oxidation of pyrite may be represented by the following chemical equations, which have been quoted by many investigators:



^{4/} U.S. Public Health Service. Acid Mine Drainage. 87th Congress, House Committee Print No. 18, April 1962, 24 pp.



Other Chemical Reactions

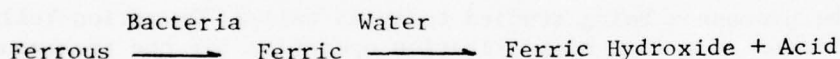
Secondary reactions take place between ferrous sulfate, sulfuric acid and the compounds in clays, shales, limestones, sandstones, and other compounds present in the coalbeds.

The acid mine water, through its course of flow by pumping, natural drainage, seepage, or diversion, enters into receiving streams. The mine water contains iron sulfate and sulfuric acid along with the sulfates of aluminum, calcium, magnesium, potassium, and sodium. Once in the receiving stream, the sulfate in the mine water undergoes further oxidation to produce ferric hydroxide and sulfuric acid. The ferric hydroxide, only slightly soluble in water and affected by temperature changes, precipitates out of solution and coats the stream with a reddish-yellow or brown sediment commonly referred to as "yellowboy".

Bacteriologic Oxidation

Many theories have been postulated as to the mechanisms of the formation of acid mine waters. The oxidation of pyrite and associated sulfur compounds depend upon the presence of oxygen, moisture, and perhaps upon the effect of natural catalytic agents, such as bacteria. The oxygen is generally considered to be supplied by air from the atmosphere.

From a kinetic standpoint, the rate of acid formation in coal mine water is greater than predicted by atmospheric oxidation alone.^{5/} It has been demonstrated that the iron-oxidizing bacteria found in these waters increase the rate of oxidation of ferrous iron to ferric iron as soluble sulfates. The reaction is as follows:



RESEARCH ON THE ACID WATER PROBLEM

In the past, research on control measures to combat acid mine drainage has been limited usually to the application of hydraulics to mining operations such as drainage control and dilution. Also mine sealing has been used for atmosphere control in the mine to prevent or to minimize

^{5/} Colmer, Arthur R., and Melvin E. Hinkle. The Role of Microorganisms in Acid Mine Water: A Preliminary Report. Science, v. 106, 1947, pp. 253-256.

pyrite oxidation. In addition, methods to neutralize the acid water were investigated and used. For strip mining operations, control measures included backfilling and reclamation.

Current research (since 1960) is being conducted on methods for treatment of acid mine water; on microbial action within the mine areas; on the abatement and control of microbial agents; and on rate and mechanism studies on the oxidation of pyrite. The demonstration projects test at-source prevention of acid formation.

The current techniques being investigated include neutralization, (direct iron removal and demineralization processes; as well as physical disposal by well injection) and improved techniques in mine drainage control. A number of active research projects involving these techniques are discussed below:

Neutralization

Neutralization is a chemical process whereby equimolar quantities of an acid and a base react to form salts and water that are chemically neutral. The basic overall reactions are as follows:

1. Acid + Alkali = Alkali Sulfate + Water.
2. Ferrous Sulfate + Alkali = Ferrous Hydroxide + Alkali Sulfate.

Alkali materials being used experimentally for neutralization of acid mine water are the oxides, hydroxides, and carbonates of calcium, sodium, magnesium, manganese, and ammonia. The activity, or rate of reaction, is high for sodium hydroxide, sodium carbonate (soda ash), and ammonia. However, because of their high cost, they are probably not economical for large-scale water-processing operations. Limes and limestones are relatively low in cost compared to soda ash and sodium hydroxide, and therefore are more widely used in acid-mine-water neutralization experiments.

One of the processes being studied today is called "Operation Yellowboy". The process is a lime neutralization operation for the treatment of acid mine water.^{6/} The neutralization process includes various unit operations such as pumping, mixing, aeration, clarification, thickening, and dewatering in a mobile pilot plant. The plant, developed by the Pennsylvania Department of Mines and Mineral Industries and with Dorr-Oliver as principal investigator, has been operated at six mine sites in Pennsylvania. The process was evaluated and treatment costs of acid mine water drainage were determined for each of these sites, except that

^{6/} Girard, Lucien, 3d., and Robert A. Kaplan. Operation Yellowboy, Design and Economics of an Acid Mine Drainage Treatment Plant. American Chemical Society, 151st National Meeting, Div. of Fuel Chemistry, v. 10, No. 1, March 1966, pp. 107-116.

sludge disposal costs were not studied in adequate detail. Plans are being made for the design of a large scale plant capable of treating 500,000 to 1,000,000 gallons per day of acid mine drainage.

Neutralization research projects are being carried out by the Bureau of Mines, industry,^{7/} Pennsylvania State University, and West Virginia University. The projects are usually financed by cooperative agreements between Federal or State Governments and industry.

Mine Drainage Control Methods

Pyrite oxidation requires only a small quantity of water and air. The moisture in the atmosphere is adequate for the basic stoichiometric reaction. The soluble acid salts that are formed remain harmlessly in place, where formed, until enough water collects to dissolve them. This collected water becomes acid mine drainage and a pollutant of streams when it flows or is pumped from the mines in sufficient quantity. Measures used to control the acid mine drainage are primarily ones that prevent water from entering the mine, either underground or strip. These measures are strictly physical diversion techniques.

The effectiveness of mine drainage control methods are in a sense unique to the specific coal mining operation. The basic principles involved with acid mine drainage, whether in strip or underground mines, are the prevention or minimizing of water seepage into the mine; the efficient moving of the drainage flow; the segregation of sulfur-bearing material from the overburden and rendering it inert by covering or by removal to a place where its acid production is limited; and the neutralization of acid pools.

Drainage control can be accomplished in strip mines by surface-water diversion ditches along the high wall of the stripping operations. Ground water from springs and streams can likewise be diverted. Through proper planning, segregation of the overburden and sulfur-bearing material, which is necessary for the prevention of secondary formation of acid water, backfilling and contouring of the strip mine area can be achieved. The reclamation of strip mine areas helps to protect the watershed by reducing acid water seepage and siltation of receiving streams.

For underground mines, drainage control can be accomplished by constructing diversion ditches around openings; by sealing streambeds to prevent water infiltration through cracks or faults caused by pillar collapse or slumps; by grouting underground areas to seal-off stream channels; and by constructing new stream channels, if necessary. Flumes are used to conduct surface water across mining properties and to dump it into approved preselected drainage channels.

^{7/} Steinman, H. E. Acid Mine Water Treatment. American Mining Congress Coal Convention, Pittsburgh, Pa., May 1966, 8 pp.

Demonstration Program

The Federal Water Pollution Control Administration in cooperation with the Bureau of Mines, Bureau of Sport Fisheries and Wildlife, U.S. Geological Survey, and State agencies is testing various methods of controlling acid mine drainage at its source or preventing its formation, and evaluating both the physical effectiveness and relative costs of the methods. Included in the study are air seals, grouting, compacted backfill, drainage diversion, and reclamation of areas disturbed by strip-mining.^{8/}

Work is currently being conducted on four demonstration projects, located at the following sites:

1. Roaring Creek-Grassy Run Watershed near Elkins, W. Va.
Area covered - approximately 35 square miles.
2. Black Creek Watershed near Mocanaqua, Pa.
Area covered - approximately 3 square miles.
3. Glen White Run-Kittanning Run near Altoona, Pa.
Area covered - approximately 10 square miles.
4. Seaton Creek in the headwaters of Slippery Rock Creek near Boyers, Pa. Area covered - approximately 7 square miles.

Mine Sealing

The Bureau of Mines has been conducting tests with mine sealing techniques at an abandoned mine near Kittanning, Pa. This program will investigate and evaluate the efficiency of sealing by analyzing the oxygen concentrations, by controlling the atmosphere of the mine, and by analyzing mine water as it leaves the mine.^{9/}

Direct Iron Removal

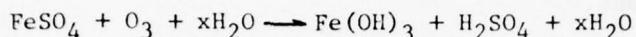
Direct iron removal processes include those methods in which the ferrous sulfate is oxidized to ferric sulfate which is completely or partially hydrolyzed to the insoluble hydroxide and precipitated out of solution. The processes in this category include ozone oxidation and impoundment oxidation.

^{8/} Bullard, W. E. Acid Mine Drainage Pollution Control Demonstration Program Uses of Experimental Watersheds. International Association of Scientific Hydrology, Publication No. 66, 1965, pp. 190-200.

^{9/} Moebs, Noel N. Air Sealing as a Means of Abating Acid Mine Drainage Pollution. American Chemical Society, 151st National Meeting, Div. of Fuel Chemistry, v. 10, No. 1, March 1966, pp. 93-100.

Ozone Oxidation

Developmental research is being investigated by Simpson and Rozelle of Wilkes College, Wilkes-Barre, Pa. ^{10/} Ozone is a powerful oxidizer, and its effect on the rate of reaction (oxidation) on ferrous iron sulfate is a function of concentration, temperature, pH, and time. The overall reaction of ferrous iron with ozone in an acid solution accompanied by hydrolysis is:

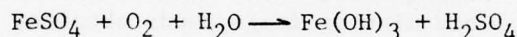


Research on the process is still in progress, and no published data are available.

Impoundment Oxidation

Impoundment oxidation, as the name implies, consists of retaining acid mine drainage in some enclosed basin. The acid waters are aerated as they enter the holding basin by various physical means such as stair-step aerators and other mechanical devices. The objective of the project is for all of the oxidized iron sulfate to hydrolyze and to precipitate out of solution as ferric hydroxide and the overflow--containing sulfuric acid--is neutralized before entering the receiving stream.^{10/}

The overall reaction is:



Demineralization

Demineralizing processes are those unit operations concerned with the separation of pollutants, which contaminate the stream, from the potable water. The pollutants in acidic streams are the iron salts and the acids formed in the mine. The various unit operations in demineralization operations include vaporization and condensation (flash distillation), diffusion and concentration (reverse osmosis), and selective ion exchange of salts and acids with specific resins (ion exchange).

Flash Distillation

Flash distillation is a vaporization and condensation process. The effluent water is heated to the vaporization point in a chamber and subsequently flashed in a series of chambers operated at lower pressures and temperatures to produce potable water and concentrated brine. The effects of scale formation, corrosion, materials of construction, limits of waste concentration, and purity of water produced are all factors

^{10/} Simpson, David G., and Ralph B. Rozelle. Studies on the Removal of Iron From Acid Mine Drainage. Symposium on Acid Mine Drainage Research. Mellon Institute, Pittsburgh, Pa., May 1965, pp. 64-82.

which are being considered in determining the engineering and technical feasibility of the process.

Westinghouse Electric Corporation^{11/} evaluated flash distillation for treating of acid mine water. Preliminary tests were made on a small scale pilot plant to determine optimum operating conditions. The data obtained were then used in the scale-up for a large 5 million gallon-per-day plant.

Reverse Osmosis

Osmosis is the process of diffusion of a solvent through a semi-permeable membrane into a more concentrated solution in order to equalize the concentrations on both sides of the membrane. Osmotic pressure is the pressure which must be applied to a solution in order to prevent osmosis into the solution. If sufficient pressure is applied to the solution, the passage of the solvent through the membrane will reverse direction.

Reverse osmosis, as related to acid mine drainage, is the diffusion of acidic water through a membrane so as to concentrate the iron salts and produce potable water.

The process has been studied extensively in the production of potable water from sea water. During 1965, field tests were made on a reverse osmosis unit using two acid mine drainage feeds obtained from mines near Kittanning, Pa. The project was sponsored by the Office of Saline Water in cooperation with the Bureau of Mines.^{12/} The objective of the project was to determine whether reverse osmosis could be performed using acid mine water without pretreatment.

Reverse osmosis was effective in converting acid mine drainage to potable water but the problem of disposing of the concentrated acidic waste exists. Disposal may be by physical means or possibly by sale of the concentrated waste. Further research is required on this problem, as well as on the problem of dissolving precipitated iron.

^{11/} Lemezis, S. Feasibility Study of Application of Flash Distillation Process to Treatment of Acid Mine Drainage Water. Symposium on Acid Mine Drainage Research, Mellon Institute, Pittsburgh, Pa. May 1965, pp. 99-101.

^{12/} Rinne, Walter W. Reverse Osmosis Treatment. American Mining Congress, Coal Convention, Pittsburgh, Pa., May 1966, 13 pp.

Deep Well Injection

Deep well injection for the disposal of brine was developed by the petroleum industry in the early 1930's. During the last decade the chemical, drug, paper, steel, ^{13/} and nuclear process industries have utilized this method for the disposal of liquid wastes and plant effluents. The same techniques have also been applied to the disposal of acid mine water drainage. ^{14/}

Three types of wells have been evaluated for acid mine drainage disposal. They are depleted gas and oil wells, dry holes, and wells drilled specifically for the disposal of acid mine water. Tentative conclusions by Vonder Linden and Stefanko were that, at least, a limited quantity of acid mine water could be pumped into subsurface strata for permanent disposal.

^{13/} Jukkola, W. H., and S. Vajda. Deep Well Sulfuric Acid Waste Disposal. Ohio Water Pollution Control Conference, June 1965, 15 pp.

^{14/} Vonder Linden, Karl, and Robert Stefanko. Subsurface Disposal of Acid Mine Water. American Chemical Society, 151st National Meeting, Div. of Fuel Chemistry, v. 10, No. 1, March 1966, pp. 101-106.

ANNOTATED BIBLIOGRAPHY

The current impetus being given to the study and preservation of our water resources has resulted in an accelerated program to investigate methods for the control of acid mine water drainage. This annotated bibliography shows the status of current research on the acid mine water drainage problem.

1. Barnes, I. Selected Properties of Mine Water and the Chemical Environment Within Some Flooded Anthracite Mines. Symposium on Acid Mine Drainage Research, Mellon Institute, Pittsburgh, Pa., May 1965, pp. 1-9.

Preliminary studies were made on the ground water samples taken from three anthracite mines in the northern anthracite field of Pennsylvania. Comparisons were made on geologic systems with the purpose of determining the chemical conditions of the natural ground water in their geologic environments. Calculated results on pH, Eh, solubility of pyrite, and thermodynamic properties are discussed and compared with actual test results made on water from the anthracite mines.

2. Benson, Arnold. Some Ecological Effects of Acid Mine Drainage in the Upper Monongahela River. American Chemical Society, 151st National Meeting, Div. of Fuel Chemistry, Pittsburgh, Pa., v. 10, No. 1, March 1966, 82 pp.

Acid mine water discharging into the Upper Monongahela drainage results in an unfavorable environmental situation demonstrated by low pH values, high acidity, hardness, and iron content. Chemical degradation is expressed ecologically in the composition of bottom fauna and fish communities. Bottom fauna, considered to be pollution indicators, constitute the food supply for fishes. Elimination of competitive and predatory fishes by acid conditions is significant in the maintenance of a thriving population of the pollution-tolerant black bullhead. Other fishes (bluegill, pumpkinseed, and green sunfish) appear to exist under marginal environmental conditions.

3. Berger, K. C., and J. L. Stroehlein. Neutralized Waste Pickle Liquor Disposal in Soils. Purdue University, Engineering Bulletin, 17th Industrial Waste Conference, 1962, pp. 1-7.

The disposal of spent pickle liquor has long been a problem of the steel industry. Ferrosul, a neutralized and precipitated pickling material, was applied to field plots. Results of the agricultural tests are given. This use of the calcium sulfates was suggested as a means for the disposal of solid products from neutralized acid mine water.

4. Bituminous Coal Research, Inc. The Acid Mine Drainage Library. Pittsburgh, Pa., 1961.

The Acid Mine Drainage Library (sponsored by the Coal Industry Advisory Committee to ORSANCO) was established at Bituminous Coal Research, Incorporated, in 1961. The objective of the library program was to collect and to maintain an information file of all publications on mine drainage and water pollution by the bituminous coal industry.

5. _____. Ion Retardation Study. Pittsburgh, Pa., 1965, (Current Research).

The objective of the project is the development of controlled acidity in streams by removing sulfuric acid, concentrating it and providing a neutralizing area for small volumes of the concentrated acid. The process is known as acid retardation. Results of preliminary tests, at Bituminous Coal Research, Inc., indicate that acid-retardation resins may be used to separate sulfuric acid from mine water.

6. Braley, S. A. Coal Mine Effluents. American Chemical Society, 151st National Meeting, Div. of Fuel Chemistry, Pittsburgh, Pa., v. 10, No. 1, March 1966, 81 pp.

The formation of sulfuric acid and acid salts is a natural oxidation reaction. Natural water entering a mine acts as a solvent and as a transportation agent for the products of the oxidation reaction.

Mine effluents are one of the most serious water pollution problems in coal mining areas. Although different from other industrial and human waste, mine effluents are among the most difficult to control.

7. Bruik, B. J. Factors Influencing the Resistance of Concrete to Sulfate Attack. U.S. Department of the Interior, Bureau of Reclamation, Denver, Colo., 1965, (Contract No. DR-23) (Current Research).

The use of special cements low in tricalcium aluminate will usually provide adequate protection against sulfate deterioration. Other factors, such as cement control, water-cement ratio, and admixtures in the form of accelerators, retarders, air-entraining agents and pozzolans have a pronounced influence on the rate and degree of sulfate attack. These factors are evaluated through use of concrete specimens subjected to an accelerated wetting and drying cycle, sulfate test, and a continuous soaking test.

8. Bullard, W. E. Acid Mine Drainage Pollution Control Demonstration Program Uses of Experimental Watersheds. International Association of Scientific Hydrology Publication No. 66, 1965, pp. 190-200.

A demonstration program for acid coal mine drainage pollution began near Elkins, W. Va., in 1964. The program is jointly being carried out by the U.S. Department of Health, Education, and Welfare, the U.S. Department of the Interior, and the State of West Virginia. The project is to determine the relative effectiveness of mine sealing, backfilling, diversion of surface water, concrete grouting of surface above underground mines and plug openings, and reclamation by means of monitoring temperature, acid load, dissolved solids load, iron and sulfate content, pH, and oxygen content in the various streams draining the demonstration area.

9. Campbell, R. S. Recovery From Acid Pollution in Four Strip-Mine Lakes. University of Missouri, Columbia, Mo., 1966. (HEW Contract No. WP 00379-04) (Current Research).

The project is to determine the changes in strip-mine lakes during recovery from acid coal mine water pollution. A series of lakes created by coal strip-mining show widely divergent biological and chemical characteristics which are related to acidity. These lakes were investigated and changes are documented within individual lakes and inferred from lake to lake as the acid climate is slowly altered. In addition to seasonal, physical, chemical and biological investigations, special effort is directed toward the evaluation of thermal characteristics and productivity.

10. Clark, C. Scott. The Oxidation of Coal Mine Pyrite. Ph.D. Thesis, Johns Hopkins University, Baltimore, Md., 1965, 90 pp.

The process of pyrite oxidation is described as an electrochemical process involving the "corrosion" of pyrite before its components are released. The electrochemical nature of pyrite decomposition dictates a thermodynamic condition, a net decrease of the free energy of the participating chemical species, that must be satisfied before pyrite oxidation can proceed. This condition has been used to determine what substances are thermodynamically able to serve as oxidizing agents to pyrite. An analysis has revealed that the ferric ion and dissolved oxygen are potential pyrite oxidizing agents. The reduction of water does not satisfy the free energy requirement.

Data from the literature on the effect of temperature, moisture, particle size, and iron-oxidizing bacteria on the rate of pyrite oxidation were analyzed. Each of these factors was found to be rate controlling but for some the rate controlling relationship was variable.

11. Clark, C. Scott. Some Factors Involved in the Oxidation of Coal Mine Pyrite and Water Quality Trends in the Monongahela River Basin. Symposium on Acid Mine Drainage Research, Mellon Institute, Pittsburgh, Pa., May 1965, pp. 35-50.

Several factors were discussed in relation to the oxidation of pyrite. They were oxidizing agents, electrochemical theory, and thermodynamics of the oxidation reaction, as well as the kinetic role of dissolved oxygen, and a refuting of the U.S. Geological Survey statement that pyrite oxidation in anthracite mines was the result of water reduction.

12. _____. A Basic Study of Acid Mine Drainage Formation. M.S. Thesis, Johns Hopkins University, Baltimore, Md., 1962, 90 pp.

Several aspects of the electrolytic decomposition of iron disulfide materials are theoretically and experimentally explored in the three chapters of this paper. In the first chapter a detailed analysis on a thermodynamic basis of a number of proposed half-reactions yields a prediction of the anode and cathode reactions in the pyrite corrosion cell. In the second chapter details of the previous acid mine water study at this university are presented and analyzed. In the previous study several chemical inhibitors were proposed and were found to be effective under specified laboratory conditions and apparently under certain field conditions. In the third chapter further verification of the proposed theory of pyrite decomposition is made.

13. Collins, A. G. Oilfield Water Research. U.S. Department of the Interior, Bureau of Mines, Bartlesville, Okla., 1965. (Contract No. BM-1601-H) (Current Research).

The basic objective of this research program is the development of analytical techniques to determine the chemical and physical properties of subsurface brines and water. These techniques will be used for the analysis of selected brines and water. The results will be used to correlate data in determining the migration and accumulation of these brines and hydrocarbons, the sources of water intrusive to oil wells, as well as new geochemical prospecting methods and more efficient methods of recovering hydrocarbons.

14. Colmer, A. R. Autotrophic Iron Oxidizers From Acid Waste Waters. Louisiana State University, Baton Rouge, La., 1966, (HEW Contract No. WP 00549-03) (Current Research).

In 1947 it was reported that autotrophic bacteria present in acid coal mine waters were capable of obtaining their energy from the oxidation of ferrous iron.

The first iron oxidizer was named Thiobacillus ferrooxidans. Other organisms were isolated and were named Ferrobacillus ferrooxidans and Ferrobacillus sulfooxidans.

The investigation of the taxonomy of autotrophic bacteria is the objective of this program. There will be three phases of the work: the morphological and cultural properties; the serological phase; and the biochemically oriented study.

15. Colmer, A. R. Relation of the Iron Oxidizer, Thiobacillus ferrooxidans, to Thiosulfate. J. Bacteriology, v. 83, No. 4, 1962, pp. 761-765.

A restudy has been made of Thiobacillus ferrooxidans secured from acid coal mine water of some northern West Virginia coal mines. The cultures were isolated from ferrous iron agar and subcultured for 85 consecutive transfers in thiosulfate broth. All were able to use ferrous iron as their energy source.

16. Corrick, John D., and Joseph A. Sutton. Copper Extraction From a Low-Grade Ore by Ferrobacillus ferrooxidans. U.S. Department of the Interior, Bureau of Mines, Rept. of Inv. 6714, 1965, 21 pp.

The application of microorganisms Ferrobacillus ferrooxidans to extract copper from low-grade ores has been explored. Criteria considered in the study were oxygen consumption, temperature, pH, particle size, nutrient copper extracted, soluble copper concentration, and other salt concentration.

17. Dugan, Patrick, and Donald Lundgren. Energy Supply for the Chemoautotroph Ferrobacillus ferrooxidans. J. Bacteriology, v. 89, No. 3, 1965, pp. 825-834.

A working model is proposed to explain ferrous iron oxidation by Ferrobacillus ferrooxidans. The ferrous ion forms a complex bond to the cell wall or membrane at a site where iron oxidase causes release of an electron. In the postulated mechanism, an oxygen molecule would be split by the oxygenase enzyme, and one oxygen atom would act as the terminal electron acceptor and be converted to water while the second oxygen atom could react with oxidized substrate to form ferric oxide or hydroxide.

18. _____. Acid Production by Ferrobacillus ferrooxidans and Its Relation to Water Pollution. Development in Industrial Microbiology, v. 5, 1964, pp. 250-257.

Ferrobacillus ferrooxidans is able to utilize the energy released by the oxidation of ferrous to ferric iron as its sole energy source, and it utilizes carbon dioxide as its sole carbon

source. $\text{FeSO}_4 + \text{O}_2$ and $\text{Fe}(\text{SO}_4)_3 + \text{H}_2\text{O}$ are believed to be rate-limiting steps indicating that the oxygenation rate is first order with respect to both concentration of ferrous iron and dissolved oxygen. It is suggested that a better understanding of the mechanism by which iron-oxidizing bacteria catalyze the reaction ferrous to ferric could lead to methods of preventing the oxidation, thereby reducing acid pollution, corrosion, and related effects.

Laboratory experiments were conducted on iron oxidation while measuring the pH and Eh of the reaction solution. The pH dropped in 120 hours to a low of 2.6. The Eh peaked at 560 milliwatts at about 70 hours of the oxidation reaction. The rise in Eh was associated with oxidation of the iron catalyzed by Ferrobacillus ferrooxidans.

19. Dugan, Patrick, and Donald Lundgren. Microdetection of Menadione, Coenzyme Q6, and Certain Related Chromatography. Analytical Biochemistry, v. 8, 1964, pp. 312-318.

A solvent extraction was performed on the chemoautotrophic bacterium Ferrobacillus ferrooxidans. Two quinoid compounds were determined in the extracts by a comparison of the column retention time to the retention time of known compounds.

20. Duncan, D. W., P. C. Trussell, and C. C. Walden. Leaching of Chalcopyrite With Thiobacillus ferrooxidans: Effect of Surfactants and Shaking. Applied Microbiology, v. 12, No. 2, 1964, pp. 122-126.

The rate of leaching of chalcopyrite with Thiobacillus ferrooxidans has been greatly accelerated by using shaken flasks in place of stationary bottles or percolators. A further increase in rate and extent of leaching was obtained by the use of surfactants. The effect of the surfactants is probably due to increased contact between the mineral surface and the organism, and shaking provides the necessary oxygen. Rates and yields obtained by the use of surfactant and shaking as aids to microbiological leaching approach those obtained with acidified ferric sulfate leaching.

21. Duncan, D. W., and P. C. Trussell. Advances in the Microbiological Leaching of Sulfide Ores. Canadian Metallurgical Quart., v. 3, No. 1, 1964, pp. 43-55.

Thiobacillus ferrooxidans leached 100 percent of the copper from museum-grade chalcopyrite in 26 days. With covellite, about half of the copper was removed in 76 days, with chalcocite, over 90 percent in 30 days, and with bornite, 100 percent in 20 days.

22. Ehlers, E. Study of the Sulfide to Sulfate Reaction Mechanism. Ohio State University, Columbus, Ohio, 1966, (HEW Contract No. WP-00340-04) (Current Research).

Warburg oxidation runs were made to derive quantitative expressions for the effect of humidity, partial pressures of oxygen and hydrogen, and concentration of ferric iron on the rate of oxidation.

Also, a special reaction system has been constructed to control the humidity and mass velocity of the vapor phase or liquid phase through a bed of pyrite.

23. Feuss, J. V., R. J. Baker, and R. J. Stroher. Some Confusing Aspects of Neutralization With Lime. Ontario Industrial Waste Conference, 11th conference, June 1964, 12 pp.

The most common contaminant of industrial waste streams is acid. Much research has been conducted to devise economic means to treat such wastes. However, there are still some confusing, if not conflicting, viewpoints in the literature on the subject.

24. Girard, Lucien, 3d. Operation Yellowboy. Design and Economics of an Acid Mine Drainage Treatment Plant. Symposium of Acid Mine Drainage Research, Mellon Institute, Pittsburgh, Pa., May 1965, pp. 102-110.

Laboratory work performed by Dorr-Oliver demonstrated the acceptability and the economics of the lime-neutralization process for the treatment of acid mine water. The data obtained were used in the design of a mobile demonstration plant which will in turn provide engineering data for the scale-up of commercial-size plants.

The acid mine drainage mobile pilot plant was built on a 40-foot by 8-foot van trailer. Unit operations of the pilot plant include pumping, mixing, neutralizing, aerating, clarification-thickening, and dewatering. The mobile pilot plant was operated at six sites in the coalfields of Pennsylvania during 1965. Reports on each of these six operations have been prepared and are available to the public.

25. Girard, Lucien, 3d, and Robert A. Kaplan. Operation Yellowboy. Design and Economics of an Acid Mine Drainage Treatment Plant. American Chemical Society, 151st National Meeting, Div. of Fuel Chemistry, March 1966, pp. 107-116.

Investigations were made on treating acid mine water at the Bethlehem Mines Corporation, Marianna Mine No. 58, by the lime neutralization process. Mine water was treated to produce a

product containing less than 6 ppm of iron and a neutral pH without flocculents. With flocculents a product was obtained containing less than 2 ppm of iron at a neutral pH at increased costs.

26. Hall, Ernst P. The Sheban Project. Symposium on Acid Mine Drainage Research, Mellon Institute, Pittsburgh, Pa., May 1965, pp. 145-160.

The Sheban project was a cooperative experiment of the Ohio Reclamation Association, Mellon Institute, Ohio Department of Natural Resources, and Consolidation Coal Company, in controlling water pollution by the impoundment of water at an unreclaimed strip mine operation. Over a period of years, the experiment proved to be successful in controlling water pollution.

27. Hanna, George P., Russell A. Brant, J. Richard Lucas, Chester I. Randles, and Edwin E. Smith. Analysis of Fundamentals of Acid Mine Drainage: A Basis for Further Investigations. Ohio State University, Water Resources Center, Rept. 175, May 1961, 76 pp.

This is a final report on a project sponsored by the Ohio River Valley Water Sanitation Commission. Recommendations are made about future research on solving the acid coal mine waste problems.

28. Hansuld, John A. Oxidation Potentials of Pyrite. Ph.D. Thesis, McGill University, Montreal, Canada, 1961, 152 pp.

The thesis study has provided a fairly detailed account of the potential behavior of pyrite in acid ferric-ferrous sulfate solutions. A new postulated pyrite oxidation mechanism was proposed. The thesis contributes a better understanding of sulfide electrode potentials as envisaged by Sato in 1958.

29. Holland, H. R., and F. R. Clark. A Disposal Well for Spent Sulfuric Acid From Alkylating Iso-Butane and Butylenes. Purdue University, Engineering Bull., 19th Industrial Waste Conference, 1964, pp. 195-199.

An alkylation unit, at Imperial Oil Enterprises, Calgary, Alberta, employs sulfuric acid as the catalyst for the operation (alkylation). As operations grew, the disposal of spent acid presented a large pollution problem. A technical evaluation of the problem indicated that deep disposal wells were practical and technically feasible. General operating data and strata formations of the well site are presented.

30. Krickovic, Stephen. Bureau of Mines Acid Mine Drainage Control Program and Joint Interior - H. E. W. Departments Acid Mine Drainage, Mine Drainage Control Program. Symposium on Acid Mine Drainage Research, Mellon Institute, Pittsburgh, Pa., May 1965, pp. 111-126.

Bureau of Mines research consists of mine sealing, laboratory studies on neutralization, demonstration project, and drainage control.

31. Landesmen, Joanne, D. W. Duncan, and C. C. Walden. Iron Oxidation by Washed Cell Suspensions of the Chemoautotroph, Thiobacillus ferrooxidans. Canadian J. Microbiology, v. 12, 1966, pp. 25-33.

Experimental variables in the manometric study of iron oxidation by washed cell suspensions of the obligate chemoautotroph Thiobacillus ferrooxidans have been examined. Optimum pH and temperature for iron oxidation are 1.75 and 40° C, respectively.

32. Lazaroff, Norman. Sulfate Requirement for Iron Oxidation by Thiobacillus ferrooxidans. J. Bacteriology, v. 81, No. 1, 1963, pp. 78-83.

The growth of Thiobacillus ferrooxidans was initially inhibited in media containing ferrous chloride in place of ferrous sulfate. Adaptation takes place, producing strains which are able to oxidize iron in high chloride, low sulfate media.

33. _____. Anionic Adaptation of Thiobacillus ferrooxidans. Syracuse University, Syracuse, N.Y., 1965, (HEW Contract No. WP-00769-01) (Current Research).

The oxidation of iron by Thiobacillus ferrooxidans requires the presence of a high relative proportion of sulfate to other anions. Adaptation occurs allowing growth of Thiobacillus ferrooxidans in iron media containing low levels of sulfate ions and high chloride ion levels.

34. Lemezis, S. Feasibility Study of Application of Flash Distillation Process to Treatment of Acid Mine Drainage Water. Symposium on Acid Mine Drainage Research, Mellon Institute, Pittsburgh, Pa., May 1965, pp. 99-101.

The application of flash distillation to process acid mine water has been approached by a two-phase study plan. The phase 1 study is to ascertain the technical and economic feasibility of the treatment of acid mine drainage by flash distillation. A full scale plant will be designed as part of the phase 2 study. The problems of corrosion, scaling heat transfer, and sludge disposal have been satisfactorily resolved.

35. Lorenz, W. C., and E. C. Tarpley. Oxidation of Coal Mine Pyrites. Bureau of Mines, Rept. of Inv. 6247, 1963, 13 pp.

Pyrite from various coal mines and coalbeds were studied to compare their composition and oxidizing characteristics. The oxidation of pyrite in solutions of ferrous sulfate and ferric sulfate and in the presence of iron oxidizing bacterium Ferrobacillus ferrooxidans was studied using a manometric technique. Results of these studies, along with laboratory technique, are presented in the report.

36. Lundgren, D. G. Physiology and Culture of Iron-Oxidizing Bacteria. Syracuse University, Syracuse, N.Y., 1966, (HEW Contract No. WP-00548-04) (Current Research).

Basic research on physiology and culture of iron-oxidizing bacteria.

37. Lundgren, Donald G., K. J. Anderson, C. C. Remsen, and R. P. Mahoney. Culture, Structure, and Physiology of Chemoautotroph Ferrobacillus ferrooxidans. Developments in Industrial Microbiology, v. 6, ch. 27, 1964, pp. 250-259.

The iron-oxidizing bacteria are found in acid coal mine waters. They contribute to the formation of sulfuric acid and ferric precipitates, both known pollutants of this environment. The "9K" culture medium was used to obtain cells for chemical, structural, and physiological analyses. Iron-oxidizing bacteria contain about 44 percent protein, 26 percent lipid, 15 percent carbohydrate, and 10 percent ash. They contain at least 2 B-vitamins, thiamin, and riboflavin, as well as 18 detectable amino acids.

38. Lundgren, Donald G., and C. A. Schnaitman. The Iron-Oxidizing Bacteria-Culture and Iron-Oxidation. Symposium on Acid Mine Drainage Research, Mellon Institute, Pittsburgh, Pa., May 1965, pp. 14-22.

The study enlarged upon some of the cultural characteristics of Ferrobacillus ferrooxidans as well as describing a system for studying the kinetics of biological iron-oxidation with intact cells.

The aim of the study was to determine the structural, physiological, and biochemical aspects of iron-oxidizing bacteria. Specifically the work dealt with Ferrobacillus ferrooxidans. Genetic experiments are planned for future research to study nutritional mutants. Transformation studies are proposed whereby Thiobacillus thiooxidans will be transformed to an iron-oxidizing autotroph.

39. May, Robert F. Strip Mine Reclamation Research, Where Are We? Min. Cong. J., v. 51, No. 4, 1965, pp. 52-55.

The U.S. Forest Service program has been designed to reduce damage to forest resources through controlled strip mining and strip mine reclamation.

40. May, Robert F., and William A. Berg. Overburden and Bank Acidity, Eastern Kentucky Strip Mines. Coal Age, v. 71, No. 6, 1966, pp. 74-75.

Overburden was sampled and analysed for pyrite content. Pyrite content was high near main coal seams and at rider seams. It decreased in overlying rock strata to about zero at the surface above the coal seam.

41. Moebs, Noel N. Air Sealing as a Means of Abating Acid Mine Drainage Pollution. American Chemical Society, 151st National Meeting, Div. of Fuel Chemistry, v. 10, No. 1, March 1966, pp. 93-100.

The Bureau of Mines has selected a small abandoned mine near Kittanning, Pa., with a highly acid discharge. The mine was sealed to prevent air from entering it.

Environmental conditions have been determined and data were collected on the volume and quality of mine discharge before sealing to evaluate the effectiveness of air sealing after mine sealing.

42. Morth, A. H., and Edwin E. Smith. Kinetics of the Sulfide to Sulfate Reaction. American Chemical Society, 151st National Meeting, Div. of Fuel Chemistry, v. 10, No. 1, March 1966, pp. 83-92.

Report defines kinetics of the rate-determining mechanism in a chemical rather than a biological system.

Results from liquid phase oxidation show that the flow rate of the fluid through the bed had no effect on the rate of oxidation. The rate remained constant for the duration of 1 to 2 week runs. Water is involved as a reaction medium rather than as a reactant.

In vapor phase oxidations the rate varied linearly with humidity and temperature. It was noted that both the oxidation rate and the partial pressure of water vapor doubled with a 10° C temperature rise.

A proposed mechanism involves the dissociation of oxygen when adsorbed on "reactive sites" of pyrite. Simultaneously,

inert gas (nitrogen) can be adsorbed and compete for these "reactive sites".

43. Normand, Russell A., and Arthur R. Colmer. Acid Soil Formations Cause Highway Maintenance Troubles. Public Works, July 1965, pp. 95-96.

Iron- and sulfur-oxidizing bacteria thrive in certain soils. Exposure to air and moisture, as in highway cuts, accentuates the acidic condition and prevents growth of cover grasses.

44. O'Connor, John T., Richard S. Engelbrecht, and M. Ghosh. Removal of Iron From Ground Waters. Symposium on Acid Mine Drainage Research, Mellon Institute, Pittsburgh, Pa., May 1965, pp. 83-91.

A survey of 31 iron removal plants (vegetation) was conducted in Illinois in 1960. The survey revealed that, at the time of sampling, the water in 18 of the 31 plants contained iron in excess of 0.3 milligrams/liter.

45. Pennsylvania State University. Research on Control of Water Quality and Coal Preparation Plant Effluent. University Park, Pa., 1966. (Current Research).

The objectives of the project are to conduct a State survey of coal preparation plants to determine the type of equipment and present operating practices used to control water quality. The results of the survey will be used to develop and present a short course on liquid-solid separation processes which will emphasize the most recent theory and the best industrial practices in the unit operations of thickening, filtration, clarification, and tailings disposal in coal preparation plants.

46. _____. The Effect of Acid Mine Drainage From Strip Mines on the Ground Water Reservoir Under Various Hydro-Geologic Environments in the Clearfield Area of Pennsylvania and the Mutation of the Water as It Moves Through the Ground Water Reservoir. University Park, Pa., 1966, (Current Research).

The project is to determine the effect of acid drainage from the strip mines on ground water. The project will investigate the interactions between infiltrating acid mine waters and the overburden in the zone of aeration and the ground water in the zone of saturation. Studies will be made on the elements of hydrogeologic environments of an acid mine drainage area.

47. _____. Control of Mine Drainage Pollution by Removal of Impurities From Drainage. University Park, Pa., 1965, (Current Research).

The study has been to investigate and to evaluate the removal of pollutants. The investigations include field studies to develop specific data on natural neutralization, and the use of coal as a means of pollutant removal. A special research report, SR-54, "A Study of the Reactions Between Coal and Coal Mine Drainage," has been published and is available for general use.

48. Pennsylvania State University. Investigation of the Technical Aspects in the Control and Disposal of Mine Water to Minimize Stream Pollution. University Park, Pa., 1965, (Current Research).

The technical and economic feasibility of permanent disposal of water contaminated by coal mine drainage by deep well injection is being studied. A special report SR-52, "Subsurface Disposal of Acid Mine Water by Injection Wells," has been prepared and is available for general use.

A coal mining company has agreed to drill a disposal well. Pennsylvania State University with Coal Research Board support has undertaken studies on permeability, porosity, and other geologic factors on this pilot well.

49. Randles, C. I. Aquatic Bacteria Related to Acid-Mine Drainage. Ohio State University, Columbus, Ohio, 1966, (HEW Contract No. WP 00147-10) (Current Research).

Studies of the roles of microorganisms in the oxidation of pyrite materials in coal are being continued with special emphasis on ferrous iron oxidation and how ferrous iron oxidation may relate to oxidation of the sulfur portion of the mineral.

Further work is being conducted on organisms found in acid water that may serve to indicate what has occurred during the formation of the acid.

50. Razzell, W. E., and P. C. Trussell. Isolation and Properties of an Iron-Oxidizing Thiobacillus. J. Bacteriology, v. 85, No. 3, 1963, pp. 595-603.

An organism isolated from acidic copper-leaching waters has been shown to oxidize ferrous ions, sulfur, and metallic sulfides but exhibit peculiar responses to thiosulfate. The name Thiobacillus ferrooxidans has been used to describe it. A stationary cultivation procedure appears superior to percolation techniques for studying the oxidation of finely divided metallic sulfides. Sodium chloride inhibits iron oxidation without preventing oxidation of metallic sulfides by the organism.

51. Reese, Robert D., and Harold L. Lovell. Some Interactions Between Coal and Water Which Change Water Quality. American Chemical Society, 151st National Meeting, Div. of Fuel Chemistry, v. 10, No. 1, March 1966, pp. 117-122.

There appears to be distinct evidence that a major change in an acid water quality used in the studies is related to the calcium carbonate minerals in the raw coal. Little, if any, association can be related to the organic coal phases.

52. Remson, Irwin. Methods of Analyzing Underground Flow Systems. Symposium on Acid Mine Drainage, Mellon Institute, Pittsburgh, Pa., May 1965, pp. 127-135.

Difficulties still exist in solving underground flow problems to determine the hydraulic characteristics and other pertinent data for many systems. Current technology has been designed mainly for porous-flow systems.

Many underground-flow problems can be solved with the aid of digital computers by using mathematical models and numerical methods of analysis.

53. Renn, C. E. The Oxidation of Coal Mine Pyrite. Dept. of Sanitary Engineering and Water Resources, Johns Hopkins University, Baltimore, Md., 1966, (University sponsored current research).

The electrochemical theory of the oxidation of pyrite and the factors controlling the rate of the oxidation are being studied. The role of dissolved oxygen in the aqueous oxidation of pyrite is being examined in the laboratory using several dissolved oxygen concentrations. An extensive literature search into the kinetic roles of surface area, temperature, impurities, and bacterial action is also involved.

54. Rinne, Walter W. Reverse Osmosis Treatment. American Mining Congress, Pittsburgh, Pa., May 1966, 15 pp.

Research investigation to determine the technical feasibility of using reverse osmosis as a means of treating acid mine drainage to separate pollutants and to produce a potable water.

55. Ryder, Linda A., and Arthur R. Colmer. An Iron Oxidizing Bacterium From the Effluent of Lead and Zinc Mines. The Proceedings of the Louisiana Academy of Sciences, v. 28, December 1965, pp. 5-11.

Samples of mine water effluents were collected from various pumps of the Eagle-Picher zinc and lead mines and the microorganisms

present in each sample were collected on a type HA Millipore filter disc. Thiobacillus thiooxidans and Thiobacillus ferrooxidans were found.

56. Schnaitman, Carl, and Donald G. Lundgren. Organic Compounds in the Spent Medium of Ferrobacillus ferrooxidans. Canadian J. Microbiology, v. 11, 1965, pp. 23-27.

The spent medium from cultures of the chemoautotroph Ferrobacillus ferrooxidans was examined for organic compounds. Pyruvic acid was identified during the culture growth cycle. Analyses of the spent medium indicated that a large portion of the CO₂ fixed by the organism was released into the medium.

57. Shearer, Robert E., and William A. Everson. Study of Bacteriophages in Controlling Acid Mine Waters. Symposium on Acid Mine Drainage Research, Mellon Institute, Pittsburgh, Pa., May 1965, pp. 23-34.

Studies have been made to isolate and to grow bacteriophages which attack the iron and sulfur bacteria. The bacterial species believed to be associated with acid production from pyrite are T. thiooxidans, F. ferrooxidans, T. ferrooxidans, and F. sulfo-oxidans. Phages have been applied to these bacteria. Varying degrees of inhibition of bacterial growth have been observed.

58. Simpson, David G., and Ralph B. Rozelle. Studies on the Removal of Iron From Acid Mine Drainage. Symposium on Acid Mine Drainage Research, Mellon Institute, Pittsburgh, Pa., May 1965, pp. 64-82.

Studies have been made to remove iron and manganese with ozone. The ozone oxidizes the iron into a form which will precipitate out of the mine drainage solution. The iron removed in this case is a relatively pure form and therefore would possibly be available for industrial use either as a raw material for blast furnace or as a paint pigment or dye. The ozone process will not eliminate all the pollutants from mine drainage; consequently mine drainage water from the ozone process would have to be processed further for the removal of acid.

59. Stumm, Werner. Oxygenation Rate of Ferrous Iron in Natural Waters. Harvard University, Cambridge, Mass., 1966, (HEW Contract No. WP-00013-7) (Current Research).

The study defines quantitatively the pertinent chemical factors which may govern the disabilization of naturally occurring colloids.

60. Stumm, Werner. Oxygenation of Ferrous Iron Properties of Aqueous Iron as Related to Mine Drainage Pollution. Symposium on Acid Mine Drainage Research, Mellon Institute, Pittsburgh, Pa., May 1965, pp. 51-63.

The work in the author's laboratories has been in connection with research on corrosion and coagulation.

The results of research on some properties of aqueous iron that appears to be pertinent to chemical behavior of ferrous sulfates in acid mine drainage are summarized in this paper.

61. Tarpley, E. C. Acid Mine Drainage: Physical, Chemical, and Biological Reactions. U.S. Department of the Interior, Bureau of Mines, Pittsburgh, Pa., 1965, (Contract No. BM-4362-7).

The study covered the pollution from acid mine drainage by investigating the effects of physical, chemical, and biological factors in pyrite oxidation.

62. Trussell, P. C., D. W. Duncan, and C. C. Walden. Biological Mining. Canadian Mining J., March 1964, pp. 1-4.

The research program on biological leaching at the British Columbia Research Council is directed toward studying those factors which affect the rate and extent of bacterial leaching of metallic sulfides.

63. Vonder Linden, Karl, and Robert Stefanko. Subsurface Disposal of Acid Mine Water. American Chemical Society, 151st National Meeting, Div. of Fuel Chemistry, v. 10, No. 1, March 1966, pp. 101-106.

Past experience with disposal wells was used as a guide. It was concluded that a well would have to be drilled for acid mine water disposal to prove the effectiveness of the method.

64. Walden, C. C. Studies of Acidphilic Chemoautotrophic Bacteria. British Columbia Research Council, Vancouver, Canada, 1966, (HEW Contract No. WP-00550-01) (Current Research).

Studies are being made on the nutrition of Thiobacillus ferrooxidans in liquid culture containing various sources of nitrogen and carbon, and a variety of ions (Cl^- , PO_4^{--} , Mg^{++} , and Cu^{++}) under various combinations of soluble oxygen, nitrogen, and carbon dioxide. Changes in the mode of the organisms' activity, after adaptation to inhibitory ions, will be investigated. The effects of aeration and amorphous substrates will be examined. The stereospecific relationship between active sites on the bacterium and arrangement of atoms in the crystal lattices of solid energy sources will be explored.

65. Walker, Joanne G., and Chester I. Randles. Mechanism of Pyrite Oxidation. Symposium on Acid Mine Drainage Research, Mellon Institute, Pittsburgh, Pa., May 1965, pp. 10-13.

This paper was very general and did not present laboratory work; rather it was a discussion of pyrite oxidation without specific details.

66. Wilson, H. A., and others. Sewage Decomposition in Acid Mine Drainage Water. Purdue University, Engineering Bulletin, 19th Industrial Waste Conference, May 1964, pp. 272-280.

The paper reports some of the results obtained from investigations to learn the mode and rate of sewage decomposition in acid mine water and the microorganisms involved.

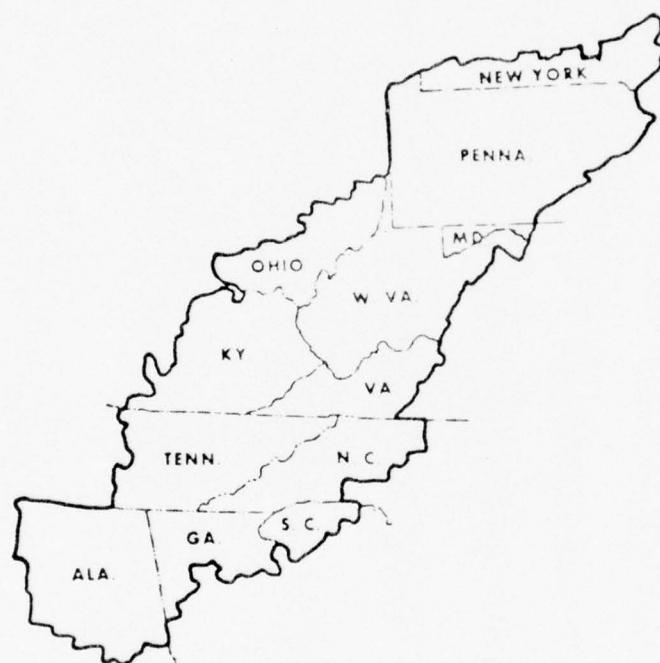
67. Zeigler, George. Coal Mining in Ohio and Its Effects on Environmental Health. Ohio Department of Health, Div. of Engineering, December 1965, 6 pp.

This paper relates to coal mining, acid mine drainage, and environmental health.

Pyrite oxidation is a normal process of nature and present technology does not offer any long-life, economically feasible, manmade products which could be applied to prevent the oxidation.

FACTORS THAT AFFECT THE FORMATION
OF COAL MINE DRAINAGE POLLUTION
IN APPALACHIA

DEVELOPMENT OF WATER
RESOURCES IN APPALACHIA



UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

AREA I MINERAL RESOURCE OFFICE
Pittsburgh, Pennsylvania

1967

APPENDIX C ATTACHMENT C

FACTORS THAT AFFECT THE FORMATION
OF COAL MINE DRAINAGE POLLUTION
IN APPALACHIA

By Walter C. Lorenz and Robert W. Stephan

UNITED STATES DEPARTMENT OF THE INTERIOR
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The work upon which this report is based was done under an agreement between the Bureau of Mines, U.S. Department of the Interior, and the Office of Appalachia Studies, Corps of Engineers, Department of the Army.

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FACTORS THAT AFFECT THE FORMATION OF COAL MINE DRAINAGE POLLUTION IN APPALACHIA

by

Walter C. Lorenz^{1/} and Robert W. Stephan^{1/}

ABSTRACT

Coal mine drainage pollutes more than 5,000 miles of streams and 13,000 acres of ponds in Appalachia. Research on the mine drainage problems was started by the U.S. Bureau of Mines in the 1920's and has been continued at various Universities, as well as by various private organizations and Federal and State agencies.

Pyrite formed contemporaneously with the formation of coal. It is associated with coal, and in rocks adjacent to the coal. It is oxidized in the presence of oxygen and moisture, and the oxidation products when dissolved in water are stream pollutants.

Current research on pyrite oxidation includes electrochemical reactions and the effects of iron-oxidizing bacteria on this oxidation.

INTRODUCTION

At the request of the Office of Appalachian Studies, Corps of Engineers, U.S. Army, Cincinnati, Ohio, a study of research literature was undertaken to determine the significance of physical, geological, chemical, and microbiological factors in the formation of coal mine drainage pollution. More than 5,000 miles of streams and 13,000 acres of ponds in Pennsylvania, Ohio, Maryland, West Virginia, Kentucky, Tennessee, and Alabama portions of Appalachia have been polluted with coal mine drainage (20)^{2/}. The mine drainage discharge has been estimated to contain more than 3.2 million tons of acid annually (49). About 72 percent of the bituminous coal and 95 percent of the anthracite produced in the United States in 1964 was mined in Appalachia (48). The Appalachian Region extends from southern New York to central Alabama and Georgia. The region includes 373 counties located in portions of the States of New York, Pennsylvania, Ohio, Maryland, Kentucky, Virginia, Tennessee,

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^{2/} Underlined numbers in parentheses refer to items in the list of references at the end of this report.

North Carolina, South Carolina, Alabama, Georgia, and all of West Virginia. Of the 373 counties, 151 produced bituminous coal in 1964 and 9 counties produced anthracite.

This report is the second in a series of reports on the coal mine drainage pollution problem to be prepared by the U.S. Bureau of Mines for the Office of Appalachian Studies, Corps of Engineers.

Mine Drainage

Acid is formed in coal mines when pyrite is oxidized in the presence of oxygen and moisture. The chemical reaction products of this oxidation are sulfuric acid and the acid salts of iron (ferrous and ferric sulfate). The pyrite is found in association with coal, clay, shale, and other rocks adjacent to and including the coal being mined.

When oxidation products of pyrite are dissolved by surface and ground waters and carried to nearby streams, the mixture is the acid mine drainage which pollutes streams in coal producing areas (29). Acid mine drainage causes discoloration of the water, creates sludge deposits in the receiving stream, and destroys fish and aquatic life essential for fish survival. The damage of the mine drainage to the streams does not end at the point where natural flow dilutes the pollution sufficiently to maintain aquatic life, but continues to lower the productive capacity of the streams for many more miles downstream. It destroys esthetic value and reduces the recreational potential of the areas in the vicinity of these streams. It also causes the water to be more difficult and expensive to treat for domestic or industrial consumption (38).

The potential volume of polluting mine drainage tends to increase as additional coal is mined. About 10 to 15 percent of the original coal reserves in Appalachia have been mined, and as additional coal is removed from the available reserves, more overlying rock strata fractures, thus allowing more surface and ground water to enter into and circulate through the voids left by mining (29).

The drainage problems in underground mines are different from those encountered in surface mines, and the practical methods of control tend to be different. Methods of control for surface mines have been demonstrated as being effective while those for underground mines have had an uncertain application history and have not been demonstrated as being completely effective. Regardless of the potential difference in control measures between surface and underground mines, the formation of acid is caused by similar mechanisms in all varieties of coal mines. The principles to be applied to prevent or minimize the formation of acid water in these mines are the same (29).

Mine Drainage History

One of the first mentions of coal mine drainage in this country was made by Gabriel Thomas (15) in 1698, when he wrote, "And I have reason to believe that there are good coals, also, for I observed the runs of water which have the same color as that which proceeds from the coal mines in Wales." In 1803, T. M. Morris (15) noted, "But the spring water issuing through fissures in the hills, which are only masses of coal, is so impregnated with bituminous and sulfurous particles as to be frequently nauseous to the taste and prejudicial to health." In 1809, Joshua Gilpin (15) visited a coal mine and wrote, "Of the coal, several feet of a mixed kind of bad coal and iron abounding in sulfur and vitro efflorescing in white and yellow crystals."

Acid mine drainage became an acute problem after World War I, following the enormous increases in coal production required to meet the needs of expanding war industry. The history of the acid mine drainage research beginning in the early 1920's involves extensive study of remedial methods and court actions (8, 14). The early research studies were mainly concerned with identifying coal mine drainage as one source of pollution in some Pennsylvania streams. Many methods were suggested for correcting this problem, but the most frequently mentioned method was the treating of the acid mine water with lime and recovering valuable neutralized by-products (8, 28). Leitch (28) proposed air sealing of underground mines as the solution to the problem. He reasoned that the elimination of either water or air would stop pyrite oxidation in coal mines. Since the elimination of water would be very difficult, he concluded that the air could be eliminated if all openings to a mine were air sealed.

The current period of research from about 1944 to the present has covered laboratory work on pyrite oxidation reactions, on methods of chemical analysis of mine water and pyrite, and on the role of bacteria in pyrite oxidation. It has included laboratory and pilot work on the practicability of neutralizing acid mine water, on sealing abandoned coal mines, and on the engineering approach to a solution for the problems of abating the formation of acid mine water and controlling acid mine drainage (1, 3, 5, 6, 19).

Soon after World War II, the Department of Health, Commonwealth of Pennsylvania, and later the National Coal Association, sponsored Industrial Fellowships at Mellon Institute for studies on acid mine water. Braley (1) investigated pyrite oxidation reactions, methods of analyses, the practicable applications of neutralizing acid water and of sealing abandoned bituminous coal mines. He advocated an engineering approach to the solution of the problem of handling coal mine water. Leathen (24) investigated the existence of bacteria in coal mine drainage. He isolated and named the iron-oxidizing bacterium, Ferrobacillus ferrooxidans (25, 26, 27).

PHYSICAL FACTORS

Formation of the Pyrite Associated with Coal Seams

In general, most of the known coal seams were probably formed, in place, in the swamps where the plants grew. The thick sequence of coal seams in the Appalachian bituminous coal basin and in the Pennsylvania anthracite fields represents a slow accumulation of silt, sand, and plant material throughout most of the Pennsylvanian Period. The present Appalachian bituminous coal and anthracite are remnants of a former more extensive area of coal deposits. The most important of the remaining bituminous coal seams in the northern part of Appalachia, including Pennsylvania, Ohio, northern West Virginia, and Maryland, are the Sewickley, Redstone, and Pittsburgh in the Monongahela Formation; and the Upper and Lower Freeport, and the Upper, Middle, and Lower Kittanning seams in the Allegheny Formation. Anthracite seams in eastern Pennsylvania are in the Pottsville Formation. In the southern part of Appalachia the more important bituminous coal seams are in the Pottsville Formation; Pocahontas, Coalburg, Sewell, Cedar Grove, and Fire Creek are some of the seams in southern West Virginia and western Virginia; Elkhorn, Hazard, and Harlan are some of the seams in eastern Kentucky; the Sewanee seam is one of the important ones in Tennessee; and the Pratt and Mary Lee are important ones in Alabama.

The origin of sedimentary pyrite associated with coal seams probably began during the putrefaction stage of the fallen vegetation. Bacteria attacked the protein of the organic material, as part of the decay process, and sulfate-reducing bacteria attacked soluble sulfates, releasing hydrogen sulfide in each instance. The hydrogen sulfide, as it was released, bubbled up through the water and sediment in the swamp reacting with soluble iron to form sulfide compounds, which eventually crystallized as pyrite (17, 30, 37, 45, 52-53).

The various places where pyrite was concentrated, such as the binders, sulfurballs, lenses, clays, shales, and rider coal bands, located in and immediately above the various coal seams, were probably initially deposited under relatively calm water conditions normally associated with swamps or basins. Considering these quiescent water conditions, the concentrations of pyrite in the initial sediments can be easily understood (45). Laboratory analyses of samples of binders, sulfurballs, and lenses indicate that these materials are often high in pyrite, occasionally as high as 94 percent pyrite (30).

Forms of Pyrite

Microscopic examination of sedimentary pyrite revealed that small microscopic- and submicroscopic-size pyrite crystals were joined together in spherical clusters 2 to 20 microns in diameter. A noticeable difference between the pyritic materials containing a high percentage of pyrite and those containing a lower percentage of pyrite was in the number of spherical clusters of small pyrite crystals. In the materials containing a high percentage of pyrite numerous clusters were joined to form a solid mass of spheres, while in those with a lower percentage of pyrite, a smaller number of spheres were dispersed among calcite and other minerals (30-31). Using X-ray analyses of the pyritic material, the iron sulfide was identified as pyrite only. Marcasite or pyrrhotite was not indicated in any of the many samples examined. This observation has been confirmed by many investigators (30).

Love and Zimmerman attributed the spherical form of pyrite in sedimentary deposits to the infiltration of pyrite grains of sizes 0.025 to 0.005 millimeters into a fossil microorganism. The spheres formed by these grains were 2 to 4 microns in diameter (31-32). Love identified the fossil microorganisms as Pyritospheara barbaria. He had isolated this spherical form of pyrite in many localities around the world, both in ancient and recent harbor sediments.

In addition to the spherical clusters of pyrite crystals, isolated crystals (cubic) of 0.5 to 5 millimeters in size have been observed in fractures in the pyritic material (binders, sulfurballs, lenses, and shales) and in coal. These crystals are probably of secondary origin (30).

GEOLOGICAL FACTORS

Sequence of Formations

It has been observed that thickness of the sediments that have deposited and compressed vary from a fraction of an inch to several feet, or more, for binders, sulfurballs, and lenses within the coal seam. The clays and shales over the coal seam vary in thickness from a fraction of an inch to 50 feet, or more. These thicknesses are probably a result of the quantity of sediments deposited and the pressure from subsequent deposits of other sediments, such as sandstones, limestones, clays, and shales. The sequence of rocks over the initial shales were probably the result of deposition by moving water. It was noted that the first materials deposited by the moving water were the heavy particles, as gravel. This was followed by sand, sand and clay, silt, silt and lime, and lime. The past rivers which existed during the Pennsylvanian Period were

often swift enough to wash away the initial sediments. This was not unusual since it has been frequently observed that sandstone often rests directly upon the coal seam. Occasionally coal has been washed away and replaced with sand or sandstone. These areas are usually referred to by miners as "want areas". The sequence of rock could be coal seam, black shale, sandstone, limestone, lime shale, sand shale, shale, and finally surface soil. Usually the rock above the initial black shale rock does not contain much pyrite. Pyrite has been found in the sequence above the shale, only, if additional coal seams, or black organic shale are present, indicating vegetation growth at levels above the initial sediment deposits. Analyses of sample cores made at U.S. Bureau of Mines laboratories usually show only fractions of percents of pyrite in the sandstones and other rocks, which were found above the initial shale rock.

Rock Formations Associated with Acid Formation in Coal Mines

The high pyrite concentrations appear to be present only in the initial sediment deposits which took place under the relatively calm water conditions normally associated with basins or swamps. The rocks commonly associated with acid formation in coal mines are the binders, sulfurballs, and lenses, within the coal seam, itself; the black shales, the clays, and the coal bands, were located immediately above the coal seam.

Braley (1) analyzed the strata above and below the coal seam from three core drillings made for exploratory purposes in northern West Virginia. He found the highest sulfur (pyrite) percentages in the shale below the Pittsburgh coal seam and in the 8-inch sections of bottom and top coal, in the shale parting (binder), and in the shale and rider coal above the seam. Similar conditions with lower sulfur (pyrite) percentages exist in the vicinity of the Sewickley and Waynesburg coal seams. He estimated that 8 inches of roof coal containing about 2 percent sulfur could produce more than 45,000 tons of sulfuric acid per square mile of mining.

Temple and Koehler (46) examined and analyzed roof strata that had been exposed by a roof fall in a northern West Virginia mine in the Pittsburgh coal seam. They found sulfur (pyrite) in varying amounts in the shale and exposed coal from 0 to 25 feet above the Pittsburgh seam.

In general it has been observed that the quality of the water draining from coal mines is dependent upon the thickness of the shale lying directly over the coal being mined. Water from mines that have a thin- to no-shale-layer over the coal often is non-acid or only mildly acid, while the mines that have thick shale over the coal have drainage that is slight to very acid.

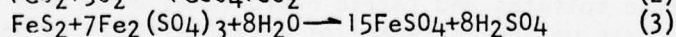
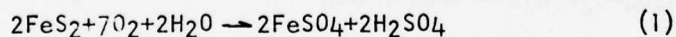
Acid coal mine drainage may often be associated with certain coal seams. In Pennsylvania, Ohio, northern West Virginia, the Monongahela Group is responsible for acid mine water pollution in varying degrees. The Sewickley and the Redstone seams produce a slight acid to acid discharge in some localities, while at others the water discharge may remain non-acid. The Pittsburgh seam sometimes produces acid water in underground mines. This varies from locality to locality, and the water discharge varies from non-acid to acid depending upon the mine location in the coal basin. The Allegheny Group, also, is responsible for acid mine water pollution in northern Appalachia. The Upper and Lower Freeport seams produce slight acid to acid water discharges in some localities, while at others the water may remain non-acid. The Upper, Middle, and Lower Kittanning seams produce slight acid to acid water discharges in many localities, while at others the water discharges may remain non-acid. The Lower Kittanning seam often discharges acid water from both strip and underground mines. The spoil from strip mining of this seam is sometimes toxic (29-30).

In southern West Virginia, western Virginia, eastern Kentucky and Tennessee, and northern Alabama, the Pottsville Groups of bituminous coal seams produce occasional slight acid water discharges, though the mine drainage pollution problem in the southern part of Appalachia is less severe when compared with the same problem in the northern part of Appalachia. The Island Creek coal seam in Logan County, West Virginia occasionally produces slight acid water discharges. The Pocahontas coal seams apparently produce little or no acid water discharges. The coal seams in eastern Kentucky and Tennessee and in northern Alabama produce occasional acid water discharges in some localities, while in others the water discharge may remain non-acid.

CHEMICAL FACTORS

Chemistry of Acid Formation

The natural oxidation of pyritic material may be represented by the following chemical equations which have been quoted by many investigators:



Secondary reactions take place between iron sulfates, sulfuric acid, and the compounds of nearby clays, limestones, sandstones, and various organic substances, which are present in mines or streams.

The intermediate steps of the natural oxidation of exposed pyritic material have often been identified as entities in dry mined-out areas of many underground coal mines. These compounds include melanterite, white to light green crystal of ferrous sulfate; copiapite, yellow to brown crystals of ferric sulfate; halotrichite, white crystals of iron or magnesium aluminum sulfate; and alunogenite, white crystals of aluminum sulfate. Yellow amorphous masses are found in worked-out mine areas, which have been identified as basic-hydrated ferric oxides or basic-hydrated ferric sulfates (29).

Chemicals Needed for Pyrite Oxidation

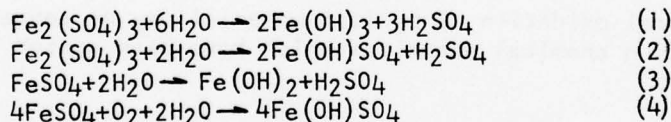
Only oxygen and water are needed to oxidize pyrite. Both of these are present in the atmosphere.

Acid Water Associated with Coal Mines

Water that is allowed to pool in abandoned sections of active mines, or in abandoned mines, dissolves the soluble sulfates, which are products of pyrite oxidation, from the pyrite. This acid water, in turn, reacts with the clays, shales, sandstones, and limestones that have fallen into the pools. Most mine water will contain such elements as iron, silicon, calcium, aluminum, manganese, sodium, potassium, magnesium, chlorides, sulfates, and traces of chromium, copper, and nickel.

Chemistry of Mine Water in Streams

When acid water from a coal mine flows into a stream, the stream immediately starts to become polluted. The reactions that take place between the mine drainage and the water in the stream may include all or part of the following:



The basic ferric sulfates and ferric hydroxides, equations (1), (2), (3), and (4), make up the characteristic yellowish-brown deposits usually noticed in streams. The common name of these deposits is "yellowboy".

The addition of acid mine drainage to a stream may or may not change the stream from alkaline to acid. The change will depend upon

the relative acid concentration in the mine drainage and alkaline content of the stream. An example of natural neutralization is the Juniata River in central Pennsylvania; several small streams, tributaries of the Raystown Branch, which were polluted by mine drainage, are neutralized by the alkalinity of the Raystown Branch within a very short distance from the discharge of the small streams.

Current Research

Promising research on pyrite oxidation, other than research using the iron-oxidizing bacteria, has been the electrochemical approach of Sato (42), Hansuld (18), and Clark (2). Sato postulated, from his potential measurements of sulfide oxidation, that oxidation takes place with a transfer of electrons. Hansuld continued the research started by Sato and defined the potential behavior of pyrite in acid ferro-ferric sulfate solutions in more detail. He postulated an electrolytic breakdown of pyrite at a point where the pyrite potential equals the solution potential. Clark described pyrite oxidation as an electrochemical process involving corrosion of pyrite before its components are released.

As part of the research effort applied to the problem of determining a mechanism of oxidation, Clark (2) and Morth and Smith (36) used the kinetic approach to define oxidation rates. Clark postulated that the concentration of dissolved oxygen is a rate controlling factor. Morth and Smith proposed that oxygen was adsorbed on reactive sites of pyrite and that the rate was a linear function of oxygen concentration.

Studies on chemical factors relating to pyrite oxidation are continuing at Ohio State University by Ehlers (16) and at Johns Hopkins University by Renn (41).

MICROBIOLOGICAL FACTORS

History of Discovery of Sulfur- and Iron-Oxidizing Bacteria

It was reported by Parr and Powell in 1919 that some type of organism might possibly explain the high acidities found in mine waters (37). They prepared two samples of coal; one was sterilized and the other was inoculated with soluble sulfate; at the end of 88 days the inoculated coal showed a decided increase in soluble sulfate over that found in the sterilized sample.

In 1944, Hinkle and Koehler (19), while conducting research on mine drainage at West Virginia University, suggested that an organism must be responsible for the rapid increase in pyrite

oxidation as compared with oxidation of pyrite in what appeared to be sterilized samples. This announcement was followed up with additional investigations at the University by Colmer, Hinkle, and Temple (5-6).

Colmer, Hinkle, and Temple reported conclusive evidence from their investigations of the presence of a known sulfur-oxidizing bacterium Thiobacillus thiooxidans in acid mine water. They identified another bacterium that oxidized ferrous iron to ferric iron and named it as a new species, Thiobacillus ferrooxidans. Both of these bacteria were found in every sample of acid mine water examined. Temple and Koehler (46) reported, that in addition to oxidizing ferrous to ferric iron, Thiobacillus ferrooxidans enhanced acid formation from pyritic material.

Separate investigations on the role of bacteria in coal mine drainage were carried out at Mellon Institute by Leathen (24-25), and Leathen and Braley (26-27). Leathen, also, isolated Thiobacillus thiooxidans from each mine water sample he examined. In addition, he identified another iron-oxidizing bacterium which he established as a new genus and designated by a new name, Ferrobacillus ferro-oxidans. In his studies with this bacterium he noted that its presence brought about increases in acidity and sulfate production from pyritic material. These increases in acid production were described as many times greater than those obtained from sterile samples.

Bacteria Associated with the Formation of Mine Drainage Pollution

In addition to the previously mentioned Thiobacillus thiooxidans, Thiobacillus ferrooxidans, Ferrobacillus ferrooxidans, other organisms which have been identified with coal mine drainage included Thiobacillus cretiverous, Ferrobacillus sulfooxidans, Ferrobacillus desulfovibrio, and Thiobacillus neopolitanus.

Much of the current research about iron-oxidizing bacteria is to learn more of the role they play in the formation of acid coal mine water. Many bacterial factors associated with pyrite oxidation have been well documented since the initial 1946-1947 discovery at West Virginia University. In spite of these studies, the actual mechanism by which the bacteria enter into the oxidation of pyrite has not been definitely established.

Many microbiologists express their belief that the iron-oxidizing bacteria, variously reported as Ferrobacillus ferrooxidans, Ferrobacillus sulfooxidans, Thiobacillus ferrooxidans, and Thiobacillus thiooxidans, are actually one and the same. To explain an apparent difference, the answer is that the bacterium has adapted

itself to different conditions and that it is also being isolated from different origins.

Current Research

The general consensus among research microbiologists is that more complete knowledge of the physiology and composition of the iron-oxidizing bacteria must be made available before a definite mechanism of pyrite oxidation can be established. Dugan and Lundgren (9) carried out solvent extraction of Ferrobacillus ferrooxidans and determined the two quinol compounds present. Schnaitman and Lundgren (35, 43) and Lundgren (33), analyzed spent medium from cultures of Ferrobacillus ferrooxidans and identified pyruvic acid, 2, 4 - dinitrophenyl hydrozone (34).

In another study by Dugan and Lundgren (10) in 1964, the role of Ferrobacillus ferrooxidans in pyrite oxidation was delineated. The bacterium uses the energy released by the oxidation of ferrous iron, Fe^{++} , $Fe^{+++} + e$, as its sole energy source and CO_2 as its sole carbon source. The pH and Eh were measured during the culture growth of the organism. The pH dropped to a low of 2.6, and the Eh rose to a maximum of 560 millivolts.

Additional studies using iron-oxidizing bacteria are continuing at Ohio State University, Syracuse University, McGill University, West Virginia University, Louisiana State University, Pennsylvania State University, Wilkes College, and U.S. Bureau of Mines. Silverman, Rogoff, and Wender (44), Randles (39), Walker and Randles (51), Walden (50), Trussell, Duncan, and Walden (47), Razzell and Trussell (40), Landesman, Duncan, and Walden (21), Lazaroff (22-23), Duncan, Trussell, and Walden (13), Duncan and Trussell (12), Colmer (3-4), and Corrick and Sutton (7) have contributed to a better understanding of the role of the iron-oxidizing bacteria in acid coal mine drainage pollution.

CONCLUSIONS

Natural environmental factors associated with the mining of coal and coal seams contribute to the phenomenon of acid formation in and around coal mines. The problem of mine drainage pollution probably started during the period before the present coal seams were being formed. Bacterial attack on the plant protein released hydrogen sulfide, which in turn reacted with iron to form pyrite. The crystal size and form of this pyrite, which is contained in the rock formations associated with coal seams, contributes greatly to the overall problem. The submicroscopic size of the crystal lends itself to rapid oxidation.

An examination of rock cover from core drillings, roof falls, and exposed highwall at strip mines, has revealed that pyrite exists many feet above the coal being mined. This factor, together with the variations in terrain, in methods of mining, and the location of pyrite concentrations contribute to the complexity of the formation of mine drainage.

Many additional core drillings, in mining areas, must be obtained and a detailed chemical analysis made to expedite interpretation of acid potential from overburden in these areas. Acid potential could be calculated if pyrite concentrations are known.

The generalized reactions of pyrite oxidation are known factors, but the mechanism of this oxidation is unknown. The progress toward an electrochemical approach to identifying a possible mechanism of reaction is promising. An eventual solution to the mine drainage pollution problem will probably result from future discoveries in this field. Current research on chemical factors of pyrite oxidation does not devote enough time or attention to the electrochemical approach to a solution to the problem.

The existence of iron-oxidizing bacteria in mines and mine drainage has been established. The catalytic effect created by these bacteria on pyrite oxidation has been well documented. The rates of reaction of pyrite oxidation increase greatly in the presence of iron-oxidizing bacteria. The mechanism of this catalyzing effect is not known, but satisfactory theories have been advanced. Progress in current microbiological research is positive enough to indicate that an acceptable mechanism of the oxidation of ferrous sulfate to ferric sulfate and pyrite oxidation will be forthcoming in the future.

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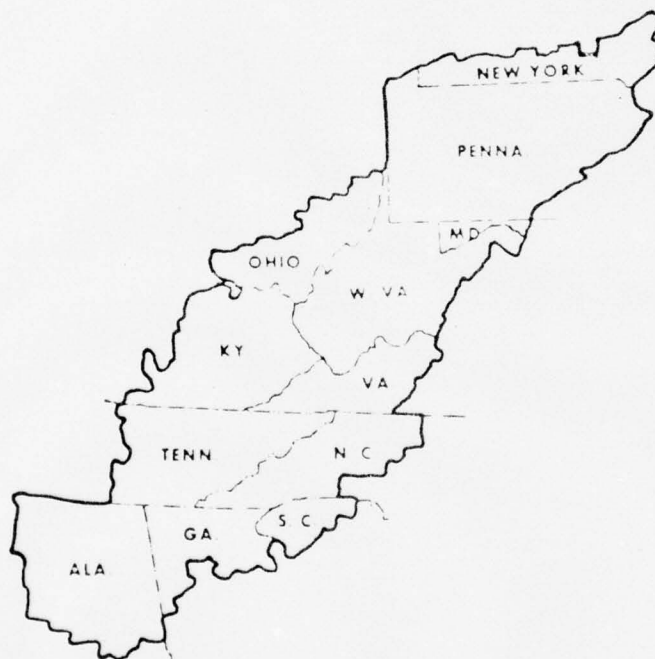
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RESOURCES IN APPALACHIA



UNITED STATES DEPARTMENT OF THE INTERIOR
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AREA I MINERAL RESOURCE OFFICE
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By Walter C. Lorenz and Robert W. Stephan

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THE OXIDATION OF PYRITE ASSOCIATED WITH COAL MINES

by

Walter C. Lorenz^{1/} and Robert W. Stephan^{1/}

ABSTRACT

A survey of the literature and current research on the oxidation of pyrite, both chemical and bacterial, is presented to indicate progress in this field.

Pyrite oxidizes when it is an anode. Oxidizing potential for pyrite has been described as being between 560 and 860 millivolts. Factors affecting the rates of pyrite oxidation are oxygen concentration, particle size, temperature, moisture, pH (hydrogen-ion concentration) and Eh (electrode potential) of the reaction, and a possible catalyst. Postulated characteristics of the oxidation reaction are based upon chemisorption of oxygen, high oxidation potential, and bacterial catalyst.

Iron- and sulfur-oxidizing bacteria increase the rate of oxidation of pyrite. These bacteria oxidize the ferrous ion to the ferric state.

Research in the past has revealed many characteristics of pyrite oxidation and on this knowledge a number of methods designed to circumvent, inhibit, counteract, or abate the pollution of mine water are being developed. None of these, however, has proved to be a panacea. The effectiveness of some is debatable, and costs are high. In the circumstances, further fundamental research designed to provide more complete knowledge of the characteristics of pyrite oxidation and to facilitate discovery of more positive and inexpensive control methods is warranted.

Although none of the current research programs carries any guarantee of success, they do show promise, and wide latitude should be given such research when new avenues of attack are found.

Among the promising lines of research are studies of the electrochemical properties, the effects of bacteria, and surface treatment of pyrite.

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INTRODUCTION

At the request of the Office of Appalachian Studies, Corps of Engineers, U.S. Department of the Army, Cincinnati, Ohio, a survey was undertaken of pyrite oxidation research as it relates to the formation of coal mine drainage pollution. Mine drainage is a major problem in the Appalachian areas of Pennsylvania, Ohio, Maryland, West Virginia, Kentucky, Tennessee, and Alabama (51).^{2/}

This report is the third of a series of reports on the coal mine drainage problem to be prepared by the Bureau of Mines for the Office of Appalachian Studies, Corps of Engineers.

PURPOSE AND SCOPE

The purpose of the report is to assess research on pyrite oxidation and to present an opinion as to whether any current program shows promise of discovering how pyrite oxidation can economically be inhibited in coal mines above the water table.

Pyrite oxidation research under chemical and microbial disciplines was reviewed in an effort to appraise progress being made toward a solution to the coal mine water problem.

BACKGROUND

In order to gain a better insight into the ramifications of current oxidation of pyrite research, a background of prior investigations is included.

1. A literature survey was made into some of the prior classic studies of early German and American scientists on pyrite and marcasite formation, the analysis of these minerals, their physical, chemical, and electrical properties, and oxidation of pyrite experiments.

2. An additional literature survey was made into the acid mine drainage research conducted by Americans from 1925 to 1960.

Classic Pyrite and Marcasite Studies

Pyrite and marcasite have often been regarded as two different forms of the same chemical formula, FeS_2 , but detailed investigations carried out by Buerger (16) disclosed that pyrite analysis corresponds very closely to FeS_2 but marcasite is definitely low in sulfur with a formula corresponding to $\text{FeS}_{1.985}$.

^{2/} Underlined numbers in parentheses refer to items in the bibliography at the end of this report.

Pyrite and marcasite were described by Allen (1-4) as two different forms of the same chemical compound FeS_2 . Marcasite was described as the unstable member under ordinary conditions, while pyrite was the stable form. He demonstrated that under certain conditions, marcasite would change over to pyrite. Allen reported repeatedly that marcasite would crystallize out in acid solutions while pyrite crystallized in alkaline solutions. Occasionally it was found that the two forms crystallized together, the proportions of each varying with the acidity of the solution.

Buerger (16) postulated a difference in sulfur composition between the two forms as being directly related to marcasite crystallization in acid solution. He postulated that the presence of sulfuric acid removes a small increment of sulfur from pyrite crystals thus continuing the formation of marcasite. He explained it as the action of H^+ upon S to form H_2S , which results in an iron rich, sulfur deficient crystal.

According to Bannister (7), chemical methods to distinguish pyrite from marcasite were not reliable unless the exact conditions of the original experiment were repeated. He believed that the use of X-ray to distinguish between pyrite and marcasite was more accurate and dependable. With X-ray, he stated that it has been possible to identify crystals, that were submitted as marcasite, as being clearly pyrite.

A chemical method of analysis to distinguish between pyrite and marcasite was described by Stokes (86) in his report on the two minerals. He described the crystallization of pyrite in alkaline solutions, and of marcasite in acid solutions. He observed that both pyrite and marcasite would crystallize when the solution was near the neutral point.

Mellor (70) reports the research of many scientists as follows:

R. Saxon (70, p. 217) observed that both ferrous and ferric sulfate appeared in an electrolyte when powdered pyrite was introduced to a 10 percent sulfuric acid solution containing iron as a cathode and carbon as an anode. When iron was used as an anode only ferrous sulfate was formed.

When pyrite was an anode in acidic solutions, I. Bernfeld (70, p. 217) observed, iron goes into the solution; also, when small current densities were used sulfur was deposited on the anode. Using the same conditions with large current densities, he noted that sulfuric acid was formed. In another experiment using pyrite as a cathode in acidic solution, he observed that hydrogen sulfide appeared at the cathode. In a series of tests in alkaline solutions, iron hydroxide was formed when the pyrite was an anode and the sulfur formed sulfuric acid; when the pyrite was the cathode sulfur formed alkali sulfide.

E. F. Smith (70, p. 220-225) discovered that a current which would completely oxidize the sulfur in marcasite in a given time would oxidize less than half of the sulfur in pyrite in the same time.

J. J. Berzelius (70, p. 223) observed that marcasite quickly became covered with an efflorescence of ferrous sulfate when exposed to moist air. He noted that the sulfate and disulfide form a galvanic couple with the disulfide being the negative pole. The disulfide, he added, is shattered by the expansive force of the growing crystals of ferrous sulfate.

Stokes (87-88) in his report, "Experiment on the Action of Various Solutions on Pyrite and Marcasite," published in 1907, described laboratory work on oxidation of pyrite and marcasite in the absence of free oxygen. From his numerous experiments, he concluded that pyrite and marcasite can be completely converted into iron oxide by alkaline solutions.

Winchell (93) discovered that the oxidation of pyrite was a slow process. He found that on treating pyrite with aerated water for one month that neither the iron nor the sulfur had gone into solution. After a 10-month experiment, he discovered that only 1/5 of a gram of pyrite or 1/15 of 1 percent of the initial sample was dissolved. In another test he demonstrated that alkaline water decomposed pyrite and marcasite to ferric oxide. The changes were slow.

In a paper on "The Exact Determination of Sulfur in Pyrite and Marcasite" Allen and Johnson (4) point out certain inaccuracies to methods of analysis from errors in oxidation by grinding, loss of sulfuric acid by volatilization, loss of sulfur during oxidation, and others.

By the use of an Ostwald Potentiometer and a Lippman Capillary Electrometer, Gottschalk and Buehler (15, 41) observed that a difference of potential existed between minerals when placed in contact and moistened. Also, they observed an increase in solution of one of any two sulfides in a mixture while a protective non-oxidizing action is exerted on the other. A difference of potential between different sulfides arranged in an electrochemical series was also noted.

Early Acid Mine Drainage Research Era, 1925-60

Leitch (61-67) of the Bureau of Mines has many publications covering his investigations on acid mine waters during the late 1920's and early 1930's. His work centered around the identification, existence, analysis, and pollution aspects of mine drainage, as well as the control of acid formation through sealing of mines. He did not evaluate the oxidation of pyrite other than simple qualitative tests

of wetting pyrite and observing acid formation through oxidation. He also immersed pyrite in water to observe the effects of sealing the mineral from contact with air.

Carpenter (19) was interested in methods of treating acid mine water, as well as in the pollution aspects of mine drainage. Much of his work revolved around acid mine water and sewage as stream pollutants. He also worked with Herndon (45-46) on a series of experiments to determine the effects of bacteriological organisms on the solubility of sulfur in coal.

The polluting effect of acid mine drainage on streams was surveyed by Herndon (45-46). His investigations included the analyses, identification, and location of the source of the acid drainage. He did not include evaluation of oxidation as part of his work except in a rough qualitative way.

Burke and Downs (17) were the first to make a quantitative measurement of the oxidation of pyrite and other sulfide minerals. Their experiments, involving control and variation of oxygen and moisture, provided data on the characteristics of the reaction. From observations of the analytical data they concluded that a surface reaction between pyrite and dissolved oxygen from the solution took place in two consecutive steps. The first reaction produced ferrous sulfate and sulfur dioxide and the second resulted in the immediate oxidation of the sulfur dioxide to sulfuric acid. They assumed that the first step was an extremely slow reaction compared to the second.

The composition and properties of coal mine drainage waters were investigated by Hinkle (47-48). Much of his time was spent observing, analyzing and otherwise investigating the properties of mine waters. He attempted to duplicate mine water formation in the laboratory with a miniature mine drainage course. Many of the tests Hinkle made were for observation purposes and not to evaluate the oxidation of pyrite on a quantitative basis. His observations and qualitative tests for ferrous and ferric iron and the sulfate radical were recorded at intervals up to about 6 months. Other observations were made on sulfurball^{3/} samples exposed to the weather.

Action of microorganisms in the oxidation of sulfide minerals was investigated by Temple (90-91). His studies included the analyses of pyrite, solution containing pyrite oxidation products, pH, and acidity of the solution.

Colmer (23-24) was a professor in bacteriology who assisted Hinkle by identifying various organisms in acid mine drainage. He later worked with Temple on further studies of organisms in mine drainage.

^{3/} Sulfurball: A term often used to denote rock-like intrusions found in coalbeds, which contained pyrite.

Several oxidizing bacteria found in acid mine drainage were investigated by Leathen (53-60). Tests were made on samples of sulfide minerals, in Erlenmeyer flasks, inoculated with sulfur- or iron-oxidizing bacteria. Samples were taken at regular intervals for analysis of pH, acidity, sulfate, and iron.

Experiments were conducted in 1956-57 by Moulton and others (72) on the "Acid Mine Drainage Problem in Ohio." The research covered a 9-month period. The report indicated that the acid formation studies were only preliminary investigations.

Inhibitors were investigated by Patrick and McCollum (75) that would retard or stop oxidation of pyrite in coal mines. McCollum made 30 tests to determine the mechanisms of the reaction of water, oxygen, and pyrites at low temperature, using several chromate and phosphate inhibitors. His experiments were very simple and consisted of suspending various samples of pyrite in agar-agar gel with various indicators. The indicators were visual checks of the reaction. The conclusion was that the reaction was electrolytic and similar to the corrosion of iron.

A longer consecutive period of time with research on the acid mine drainage problem has probably been spent by Braley (9-12), than any other individual. Braley's work (17) included a quantitative determination of the difference in reaction rates between pyrite crystal, marcasite minerals, and sulfurball material. He evaluated mine seals, mine drainage controls, neutralization of acid mine water, and inhibitors.

CURRENT CHEMICAL OXIDATION OF PYRITE RESEARCH

Current^{4/} laboratory research by American and some foreign scientists on oxidation of pyrite, by both chemical and microbial disciplines, is more sophisticated than was the acid mine drainage research of an earlier period. The research scientist of the period from about 1925 to the early 1960's, approached the acid mine drainage problem with an assumption that pyrite oxidation was a more or less known factor easily identified by the stoichiometric reaction commonly quoted in their reports. These earlier scientists, searching for solutions to the acid mine drainage problem, concluded that the answers were either to treat the mine drainage, to seal the mines, or to provide a measure of mine water diversion or control. Scientists now are approaching the problem with an assumption that the oxidation of pyrite is not fully known and that the reaction must be more clearly understood before the problem can be solved. The aspects that are being studied include:

- a. Electrochemical oxidation
- b. Kinetics of oxidation
- c. Thermodynamic oxidation
- d. Microbial oxidation.

^{4/} From the late 1950's up to and including the present time.

Electrochemical Oxidation

Evidence that oxidation of sulfide ores was an electrochemical process, similar to the corrosion of metals, was presented by Habashi (42). He demonstrated that ions are oxidized at anodic areas, and are reduced at cathodic areas. On that basis, Habashi demonstrated that an electro-potential brought about a reduction to the metal.

Sato (77-78) divided his pyrite and other sulfide oxidation research into a field and a laboratory study. His theory of oxidation by an electrochemical reaction was demonstrated in the field work by ranges of Eh (electrode potential) and pH (hydrogen-ion concentration) values for the weathering environment of various ore bodies. In his laboratory study, he measured the single electrode potentials of sulfides, including pyrite. This research was conducted with a polished pyrite electrode in ferrous sulfate solution, the results of the tests indicated a potential for the reaction $\text{FeS}_2 + 3\text{H}_2\text{O} \longrightarrow \text{Fe}(\text{OH})_3 + \text{S}_2 + 3\text{H} + 3\text{e}$. He postulated that the sulfur in the equation was released as sulfur molecules rather than crystalline sulfur and that the sulfur molecules are immediately oxidized to sulfate ions. Sato also observed that the slowness of pyrite oxidation under the influence of some oxidation agents may be explained by the high oxidation potential needed for the oxidation reaction. Potential requirements for pyrite oxidation are described as usually being in excess of 650 millivolts.

Baas Becking, Kaplan, and Moore (6) collected data on oxidation-reduction potentials and pH for various natural environment situations. For a pyrite oxidation example, they recorded an oxidation reaction where the pH dropped to 3.1 and the Eh rose to 650 millivolts. Higher oxidation potentials were only obtained in the presence of bacteria, which resulted in a pH drop to 2.0 and Eh rise to 860 millivolts.

Pyrite oxidation was compared by Clark (21), in his Ph.D. thesis, (Johns Hopkins University), to an electrochemical corrosion of iron. He noted that a close relationship exists between electrode potentials of sulfides and their oxidizing behavior. This factor led to the establishment of an electrochemical series of sulfides similar to the series of metals.

An electrochemical investigation of pyrite electrodes in acid ferric-ferrous sulfate solutions was made by Hansuld (43-44). He studied the oxidation reaction mechanism, and the replacement of iron by copper. Hansuld's work demonstrates that the pyrite potentials are related to solution potential and that an electrolytic breakdown of pyrite occurs when the potential of the pyrite equalled the potential of the solution. This electrolytic equilibrium occurs in the vicinity of 660 millivolts. Hansuld postulated a symbolic oxidation-reaction mechanism in acid environments to be $\text{FeS} + \text{Fe}^{++} \longrightarrow \text{Fe}^{+++} + \text{S} + \text{e}$.

Oxidation-reduction (redox) potential was defined by ZoBell (98-100) as a quantitative measure of how reducing or how oxidizing the system is with reference to some standard. When referred to the standard hydrogen electrode, the redox potential is expressed as Eh in terms of volts. The Eh of a system is analogous to the pH, and the two are closely related. The oxidation and reduction reactions involve electron migrations, or an exchange of electric charges, which can be measured in terms of e.m.f., or electrode potential differences. An oxidizing system will have a positive electrode potential, while a reducing system will have a negative electrode potential.

Kinetics of Oxidation

Chemical kinetics is concerned with the rate of chemical reaction, the factors which influence the rate of reaction, and the explanation of the rate in terms of the reaction mechanism. Those factors, which affect the rates of oxidation of pyrite, include temperature, oxygen concentration, particle size and surface area, texture, moisture or humidity, pH and Eh of reaction, imposed potential, and the presence or absence of a catalyst.

Kinetic studies in the past usually have not included combinations of chemical and physical factors, but usually only one factor at a time. A principal difficulty in using a combination of factors has been inadequate research techniques for evaluating the influence of more than one factor at a time.

Shmuk (82) observed that adequate results from kinetic investigations have demonstrated that the rate of pyrite oxidation carried out at room temperature and normal pressure has been slower than observed in nature. The slow reactions indicate that some form of catalyst was needed if the oxidation of pyrite rate noted in laboratory tests was to equal the rate observed in nature.

Morth (73), and Morth and Smith (74) observed that pyrite oxidation rate was dependent on the kinds of pyrite used and also upon temperature, oxygen content, surface area, texture, and particle size. Morth studied the oxidation rate in a Warberg apparatus. It was observed that increases in temperature increased the rate of oxidation; each 10-degree temperature rise nearly doubled the rate. In liquid phase tests, Morth and Smith discovered that the oxidation rate was a function of the temperature rise. They observed that oxidation rate was a function of oxygen concentration; maximum oxidation took place in 100 percent oxygen atmosphere.

Kinetic studies on pyrite oxidation in aqueous suspensions, reported by McKay and Halpern (71), showed that the rate-determining step was a heterogeneous reaction, where an oxygen molecule attached itself to the pyrite surface; this was a fast, first-order reaction.

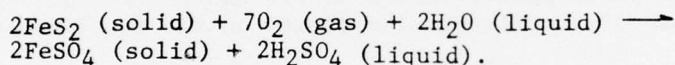
A second, slower reaction took place when a second oxygen molecule attached itself to the pyrite surface. They observed that the rate of oxidation was proportional to the pyrite surface area and to the oxygen partial pressure. A postulated mechanism of reaction was a rapid chemisorbed oxygen molecule at each FeS_2 site; as $\text{FeS}_2 + \text{O}_2 \longrightarrow \text{FeS}_2\cdot\text{O}_2$; this was followed by a slower reaction when a second oxygen molecule was chemisorbed; $\text{FeS}_2\cdot\text{O}_2 + \text{O}_2 \longrightarrow (\text{FeS}_2\cdot 2\text{O}_2) \longrightarrow \text{FeSO}_4 + \text{S}^0$; the S^0 was further oxidized to sulfuric acid.

A study was made by Clark (21) of the kinetics of oxidation in an aqueous solution. He controlled the dissolved oxygen content, the temperature, the moisture, and the particle size in his experiments. He observed that the dissolved oxygen concentration was a rate controlling factor; the order of the reaction was a power of about two-thirds. Temperature, moisture, and surface area were also found to be rate controlling, but the rate-controlling relationship for each factor appeared to be variable.

Thermodynamic Oxidation

Chemical kinetics in oxidation of pyrite research has been a study of the rate of the reaction as it took place, while chemical thermodynamics has been concerned with change from one state to another of the same reaction in a state of equilibrium.

Shmuk (82) calculated the equilibria and free energy constants of pyrite oxidation using the equation:



He concluded that high values of the equilibria constants enabled pyrite oxidation to proceed to completion at room temperature and pressure.

Thermodynamic calculations for oxidation of coal mine pyrite were made by Clark (21). He demonstrated from these calculations that the pyrite was very insoluble. He observed that simple dissolution of pyrite without oxidation was not able to account for the large quantities of oxidized products present in waters near coal mining areas. He also concluded that on a thermodynamic basis ferric ion and dissolved oxygen served as oxidizing agents for pyrite oxidation.

CURRENT BACTERIAL OXIDATION OF PYRITE RESEARCH

Iron- and sulfur-oxidizing chemoautotrophs (bacteria) have been isolated on many occasions from acid mine waters. In this country, they were isolated by Colmer and Hinkle (23) in 1947; Leathen and

Madison (60) in 1949; Colmer, Temple, and Hinkle (24) in 1950; Bryner, Beck, Davis, and Wilson (14) in 1954; Brant and Moulton (13) in 1960; Corrick and Sutton (25) in 1961; Ehrlich (36) in 1963. In Canada, such bacteria were isolated by Razzell and Trussell (76), and Lazaroff (52) in 1963. In Europe, the same bacteria were isolated by Ashmead (5) in 1955, and Zarubina, Lyalikova, and Shmuk (97) in 1959. The studies about the bacteria have shown that the isolated microorganisms accelerate the rate of oxidation of pyrite and other sulfide minerals.

The use of Ferrobacillus ferrooxidans to remove pyrite from coal was investigated by Silverman (80-81). He concluded that the bacterium oxidized the ferrous ion to the ferric state, and that the ferric sulfate would then oxidize pyrite to ferrous ions and sulfuric acid. The cycle would repeat itself until the pyrite was consumed.

Sutton and Corrick (89) used several different species of iron- and sulfur-oxidizing bacteria in studies of their role in the oxidation of certain copper sulfide minerals. The mechanism that they report is an oxidation of the copper mineral by ferric sulfate. The reaction products would be copper sulfate, ferrous sulfate, and sulfuric acid. The bacteria would again oxidize the ferrous sulfate of the reaction products to ferric sulfate. The cycle would continue to repeat.

Dugan and Lundgren (32-34) made a study of the mechanism by which iron-oxidizing bacteria catalyze the reaction of $\text{Fe}^{++} \rightleftharpoons \text{Fe}^{+++}$. They used measurement of hydrogen ion concentration (pH) and electrode potential (Eh) to define the ferrous to ferric ion oxidation. They observed that the pH dropped from 3.5 to 2.6 and the Eh rose to 560 millivolts because of the microbial activity on the testing medium.

The structure and composition of iron- and sulfur-oxidizing bacteria were studied by Lundgren, Anderson, Remsen, and Mahoney (68) in an effort to relate specific structures and composition with known physiological and biochemical information. Iron-oxidizing bacteria were found to contain about 44 percent protein, 26 percent lipid, 15 percent carbohydrate, and 10 percent ash. Electron micrographs revealed cell walls, cytoplasmic membranes, and some organelles that are characteristic of gram-negative organisms. A study was also made of the effects of certain inorganic and organic compounds, added to the growth medium, on iron oxidation by Ferrobacillus ferrooxidans. The tests accomplished were made to acquire knowledge of the nutrition and metabolism of the organism.

The mechanism of the ferrous ion oxidizing to the ferric ion in the presence of Ferrobacillus ferrooxidans was investigated by Dugan and Lundgren (32). To explain the results of their research, they postulated a model of the bacterium in contact with ferrous sulfate. The experiment demonstrated the possibility that an iron complex

involving oxygen would become attached to the bacterium. This initial complex would then be oxygenated but not oxidized until an electron was transferred to the complex. The complex was formed in the solution or on the cell surface and was linked with the ferrous ion, resulting in a release of an electron. Since sulfate was a requirement for ferrous oxidation, they postulate that the sulfate ion could be the initial transfer link between iron and the cell.

Dugan and Lundgren (34) investigated the presence of quinoid compounds, which are strong electron-attracting groups. Using electron capture-gas chromatography, they were able to identify several related quinoid compounds in the bacterium, Ferrobacillus ferrooxidans.

BACTERIAL SULFATE REDUCING RESEARCH

A chapter on sulfate reducing bacteria is added to this report as a reminder that these bacteria might be useful in solving the acid mine water problem. There is no current research specifically oriented to the use of the sulfate reducing bacteria in acid mine water studies.

Sulfate reduction is widespread and the reducing bacteria have been found in many different environments. Sulfate-reducing bacteria have, in fact, been isolated from soil, ditch and canal mud, sewage, artesian wells, dug wells, curative muds, mineral waters, sea and ocean muds and sediments, sand dunes and clay, oil well waters, bogs, waters of lead mines and coal mines, and rocks (18, 35, 37-39). The bacteria are active in sediments of sea water and brackish waters, and can be recovered from agricultural soils as well as from water-logged soils. They are not active except under strongly reducing conditions (83-85, 98-100).

The sulfur cycle in sediments and soils is a result of three kinds of microorganisms. They are (1) the oxidizing-chemoautotrophic bacteria, which oxidize sulfur and sulfides to sulfates; (2) the sulfate-reducing bacteria, which reduce the sulfate to sulfide; and (3) certain heterotrophic bacteria, which reduce the sulfur of plant protein to hydrogen sulfide (39).

The reducing bacteria are found in an alkaline environment in black mud. It is only upon oxidation that the environment becomes acid. When the environment becomes acid, sulfide formation caused by reducing bacteria tends to cease and the reducing organisms are temporarily destroyed. The shift from alkaline to acid occurs on aeration, and it is accompanied by the formation of the ferrous and ferric ions (39, 83, 85, 98-100).

Freke and Tate (37) conducted laboratory experiment with sulfate-reducing bacteria growing under anaerobic conditions to remove iron

from iron-containing solutions. The complete removal of iron from ferrous-ferric sulfate solutions as the insoluble sulfide was achieved. Under certain conditions a magnetic iron sulfide was produced.

DISCUSSION

During the 19th century and early part of the 20th century, German and a few American scientists were investigating the properties of pyrite and other minerals. The electrical properties were reported early and persistently throughout much of this period (70). When pyrite is an anode, in acidic solutions, iron goes into solution and sulfuric acid is formed. With pyrite as a cathode, in acidic solution, hydrogen sulfide appears at the cathode. When pyrite is an anode, in an alkaline solution, iron goes into solution and is converted into hydroxide and the sulfur forms sulfuric acid. With pyrite as a cathode, in alkaline solution, the sulfur forms alkali sulfide. Pyrite is converted into ferrous sulfate and sulfuric acid when exposed to moist air; the efflorescence of ferrous sulfate on the pyrite crystals forms a galvanic couple with the pyrite becoming the negative pole; the pyrite is shattered by the expansive force of the growing crystals of ferrous sulfate. An imposed current on pyrite as an anode will completely decompose the mineral.

The more modern investigations, after 1920, were directed to applied use of the basic pyrite research as a means to explain the existence of certain secondary ore deposits; as well as knowledge of the water polluting properties of coal mine drainage.

Geochemists investigated the oxidation of sulfides, including pyrite, as a source of acid which reduced certain metal complexes and contributed to a redistribution and deposition of these metals to present secondary ore deposits. One of the primary tools used in laboratory experiments was to measure the pH and Eh of the oxidizing sulfide. The pH and Eh values were compared to onsite field conditions at the ore deposit.

Laboratory studies have been made on kinetics of pyrite oxidation, thermodynamics of pyrite oxidation, and on electrochemical reactions to describe the oxidation of pyrite as corrosion.

In the presence of adequate oxygen concentration and moisture, pyrite oxidizes with increases in acidity to a pH of about 2, and increases in electrode potential with Eh factors reported between 560 and 860 millivolts. Oxidation of pyrite will take place at room temperatures without any particular regard for particle size of the test sample.

The oxidation of pyrite found in association with coal and coal seams appears to be catalyzed by certain iron- and sulfur-oxidizing

bacteria. The bacteria have an effect that has not been completely identified but they do tend to increase the oxidation rate to many times more than the oxidation rates that have been recorded with pyrite oxidizing in sterile solutions.

The iron-oxidizing bacteria oxidize ferrous sulfate to ferric sulfate, and this has been the only reaction attributed to these bacteria. Because of this, the mechanisms of the oxidation of pyrite have usually been advanced by microbiologists as oxidation of pyrite by the ferric ion which is reduced during the reaction to the ferrous ion and sulfuric acid. The ferrous ion is then again oxidized by the iron-oxidizing bacteria to the ferric form. The cycle repeats itself continuously until all pyrite has been oxidized.

New research with iron-oxidizing bacteria has identified the chemical constituents of the bacteria and its electron transferring ability, which appears to be the mechanism of oxidation of ferrous to ferric sulfate.

The electrical properties of pyrite and the effect of electric currents upon pyrite have been known since the 19th century. In reference to these properties, pyrite oxidation has occasionally been referred to as a corrosion reaction.

CONCLUSIONS

Much has been learned in the past about pyrite oxidation and its relationship to mine drainage pollution. This serves as the basis for current abatement methods. But the limitations and high cost of treatment of present methods encourages further search for more complete understanding of the factors that control pyrite oxidation.

This review did not reveal any current research program that appeared to be on the threshold of radical discoveries that would provide a panacea for the acid mine drainage problem. However, they do show promise of making significant contributions to the fund of knowledge that will be required to develop effective and economic methods for preventing the formation of pollutants in mine drainage. Research on electrochemical properties, the influence of bacteria, surface treatments, and reaction inhibitors are the more promising programs at present.

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SURVEY OF COSTS ON METHODS FOR CONTROL
OF ACID MINE DRAINAGE POLLUTION

DEVELOPMENT OF WATER
RESOURCES IN APPALACHIA



UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

AREA I MINERAL RESOURCE OFFICE
Pittsburgh, Pennsylvania

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APPENDIX C ATTACHMENT E

SURVEY OF COSTS ON METHODS FOR CONTROL OF
ACID MINE DRAINAGE POLLUTION

by Robert W. Stephan and Walter C. Lorenz

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Robert W. Stephan^{1/} and Walter C. Lorenz^{1/}

ABSTRACT

This report presents capital investment and operating costs on the various processes and methods available for the abatement of pollution due to acid coal mine water drainage. The abatement measures include neutralization, iron removal, demineralization, and physical disposal by deep well injection.

Cost data are presented on the reclamation of land disturbed by surface and strip mining operations. A summary of available data relating the various size plants for treating acid mine water is reported for the various processes for abatement of pollution. The costs of pollution abatement measures as determined in this survey range from less than \$0.07/1,000 gal. to \$1.13/1,000 gal. of acid mine water treated.

INTRODUCTION

At the request of the Office of Appalachian Studies, Corps of Engineers, Department of the Army, Cincinnati, Ohio, an engineering and economic evaluation survey was undertaken on the costs of the various methods and processes available for the control of pollution from acid mine water drainage.

The water in more than 5,000 miles of streams and 13,000 acres of ponds (10)^{2/} in Appalachia has been polluted by coal mine drainage. About 72 percent of the bituminous coal and 95 percent of the anthracite produced in the United States in 1964 was mined in the Appalachian States of Alabama, Georgia, Kentucky, Maryland, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia (2).

This report is the fourth in a series of reports on the coal mine drainage pollution problem to be prepared by the Bureau of Mines for the Office of Appalachian Studies, Corps of Engineers.

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^{2/} Underlined numbers in parentheses refer to items in the list of references at the end of this report.

Purpose and Scope

This report surveys and presents the current status of cost data available for the various processes and methods for the abatement and control of acid mine water pollution of our natural waterways. In addition, data on reclamation techniques and cost for recovery of disturbed land resulting from surface and strip mine operations are reported.

Data on which this report is based were obtained from field interviews and inspections, and correspondence with officials of coal companies, universities, research organizations, Federal and State agencies, and literature research.

The costs of each process on a unit basis is presented. Basically, the report is confined to reporting the results of present technology for treating acid mine water pollution and methods for reclamation of land disturbed by surface and strip mine coal operations.

EVALUATION PROCEDURES REQUIRED FOR THE DETERMINATION OF THE UNIT OPERATIONS AND PROCESSES APPLICABLE TO THE TREATMENT OF ACID MINE WATER

The engineering and economic evaluation of any unit operation or process for treating coal mine water are a direct function of the quantity and quality of acid mine water to be processed. In practically all processes used for treating mine water, the following conditions are of major significance as they will dictate not only the size of equipment and plant but also pretreatment requirements and materials of construction. These conditions are:

1. Total solids.
2. Concentration of calcium and magnesium.
3. Concentration of sulfate ions.
4. Concentration of iron and manganese.
5. Total acidity and pH of water.
6. Volume of water.
7. Variations in items (1-6) above.
8. Sludge disposal (if applicable).
9. The number and locations of effluents from a mine (if applicable).

Barthauer (1) has presented a realistic approach in classifying acid mine water by types. The classification is fundamental in assessing the feasibility and practicability of any of the proposed processes. The classification of typical mine water is given in table 1.

TABLE 1. - General classification of mine water quality (1)

	Type I	Type II	Type III
pH.....	7.6	6.5	3.0
Acidity (ppm as CaCO ₃).....	-361	-193	+2370
Iron (ppm as Fe).....	0	60	619
Calcium (ppm as Ca).....	55	205	495
Magnesium (ppm as Mg).....	10	70	165
Manganese (ppm as Mn).....	0	3	2
Aluminum (ppm as Al).....	0	0	65
Sulfate (ppm as SO ₄).....	830	1750	4430

The figures are indicative of mine water quality but they are not to be considered as absolute criteria. Type I discharge is water which enters the mine but is removed before any of the iron salts and hydroxides can be leached out of the mine. Type II discharge is considered alkaline water and the water contains significant amounts of iron which require some form of treatment. Type III discharge is considered acid mine drainage and it has a high acidity, high iron content, and a low pH.

PRESENT AND PROPOSED TECHNOLOGY AVAILABLE FOR CONTROL OF MINE WATER POLLUTION

The application of known chemical unit operations and processes is being evaluated by various investigators as a means to control coal mine water pollution. In many instances, the applicable technology has been modified to accommodate these liquid wastes. The objectives of mine drainage control have been to prevent the pollution of our natural water resources by acid and metal sulfates associated with coal mining. The methods being investigated and evaluated include the prevention of water entry into the mine through infiltration, relocation of streambeds, mine sealing, segregation of acidic and non-acidic water within the mine area by channeling and pumping out the water as rapidly as possible, and the treatment of the mine water that has become polluted by these acid and metal sulfates leached from the mining operations.

The technology currently being investigated and evaluated include neutralization, iron removal and demineralization processes; disposal by deep well injection; mine drainage control; and reclamation of disturbed strip mined areas.

Neutralization

Neutralization is a chemical process whereby equimolar quantities of acid and base react to form salts and water that are chemically neutral. The basic overall chemical reactions are:

Sulfuric Acid + Alkali \longrightarrow Alkali Sulfate + Water

Ferrous Sulfate + Alkali \longrightarrow Alkali Sulfate + Ferrous Hydroxide

Ferric Sulfate + Alkali \longrightarrow Alkali Sulfate + Ferric Hydroxide

The basic steps required for the treatment of acid mine water consists of a simple alkali neutralization device--alkali in a fixed bed box, rotating drum, or hopper with a mechanical feeder--which would facilitate the contact of the alkali material and acid mine water. Additional refinements would include facilities for the preparation of an alkali slurry which would, with proper instrumentation, meter the slurry at a rate corresponding to variations in quantity and quality of acid mine water to be treated.

In assessing the engineering and economic feasibility of the neutralization process, the variables to be considered are the quality and quantity of the acid mine drainage. The principle variable is the composition of the acid mine water to be treated. The more important constituents to be evaluated are iron content, sulfate content, and pH values. The quantity or volume of discharge directly dictates the size or specifications for major items of equipment required for neutralization of the acid waters. Type III discharges are the chief pollutants to our waterways and streams and constitute the main problem of acid mine drainage from coal mining operations (table 1) (1).

The average amount of hydrated lime, for neutralizing a typical acid mine water is about 7-1/2 pounds per 1,000 gallons of acid water treated. This quantity of lime, in most cases, will produce a water of pH of 8 to 8.5. At a rate of 500,000 gallons per day, about 3,750 pounds of lime would be used. Hydrated lime in bulk costs \$19.25 per ton f.o.b. lime plant. Therefore, the lime costs would be about \$36.10 per day. Labor cost at \$30 per day plus incidental costs of \$14 for a total cost of \$80.10 per day. The average treatment cost would be approximately \$0.16 per 1,000 gallons of acid mine water. Table 2 illustrates the relative costs of various alkali materials for neutralization of sulfuric acid.

Operation Yellowboy

One of the neutralization processes being tested and evaluated rather extensively is Operation Yellowboy. The project is being sponsored by the Coal Research Board of the Commonwealth of Pennsylvania. The project consists of four research and development phases, as

TABLE 2. - Raw material costs for neutralization of sulfuric acid in acid mine water ^{1/}

Material	Use factor on 100% alkali basis ^{2/}	Equivalent acid lbs. H ₂ SO ₄ /lbs. alkali	Cost per ton ^{3/}	Cost per ton, H ₂ SO ₄ neutralized
CaO - (100% Basis).....	1.00	1.75	-----	-----
Limestone, High calcium Lump.....	.56	.98	1.60	1.64
Pulverized.....	.56	.98	3.50	3.57
Lime, hydrated.....	.76	1.33	19.25	14.47
Calcium carbonate Air floated (100% Basis).	.56	.98	13.50	13.77
Soda ash - 58% (Na ₂ O) Bags (CL).....	.52	.915	40.00	43.70
Bulk (CL).....	.52	.915	32.00	34.97
Caustic soda, 76% flake 400 lb. drums (works)....	.69	1.20	111.00	92.50
Ammonia, Anhydrous.....	1.65	2.88	92.00	31.94

- ^{1/} Source - Oil Paint and Drug Reporter, May 15, 1967 issue.
^{2/} Use factor equals lbs. CaO to which 1 lb. alkali is equivalent.
^{3/} Does not include freight costs.

follows: Feasibility Study and Site Selection; Pilot Plant Design and Fabrication; Operations; and Process Evaluation (engineering and economic) (5, 8).

The overall objectives of the Operation Yellowboy project were to obtain the necessary design data that would facilitate pilot plant scale-up to full or large scale operations required for acid mine water treatment plants. To facilitate the obtaining of the required data, a mobile pilot plant was designed, constructed, and operated by Dorr-Oliver, Inc., for the Commonwealth. The unit operations involved in this portable pilot plant are pumping, mixing, aeration, clarification, thickening, and dewatering.

The flow sheet for the Operation Yellowboy process is presented in figure 1.

The acid mine water, pumped into the plant, first goes to a flash mixer containing a hydrated lime slurry. The rate of acid mine drainage is controlled by flow metering, valving, and pump motor speed. A screw feeder regulates the amount of lime required to continuously neutralize the incoming acid mine water. The neutralized water, containing principally iron compounds and calcium sulfate, then flows by gravity to the aerator. In the aeration phase, the ferrous hydroxide is further oxidized to ferric hydroxide. The aerated slurry, then flows by gravity into a thickener. Here, chemical flocculents are added to increase the settling rate of the solids. Treated mine water overflows the thickener while the thickened solids, ferric hydroxide and calcium sulfate, are pumped from the bottom of the thickener to a bowl centrifuge for additional dewatering and subsequent sludge disposal.

The pilot plant was tested at six mine sites: Bethlehem Mines Corp., Marianna Mine No. 58; Paul Moore's Farm, Little Scrubgrass, Clinton, Pa.; Young and Son Coal Mine, Butler County, Pa.; Morea Strip Pit, Schuylkill County, Pa.; Blue Coal Corp., Loomis No. 4 Shaft, Ashley, Pa.; and Dodge Mine, Warwick, Scranton, Pa. The Operation Yellowboy process has been evaluated and costs for treatment of the acid mine drainage have been determined for each of the sites. The results of these tests are shown in table 3.

The capital investment costs calculated for Operation Yellowboy range from \$9,850 to \$1,094,000 dependent upon flow rate and acid water quality. The annual operating costs calculated from scale-up design from bench scale operation range from \$10,236 to \$475,500. This is equivalent to \$0.007 to \$1.09 per 1,000 gallons (table 3). The capital investment and operating costs for each of the sites evaluated is given in table 3.

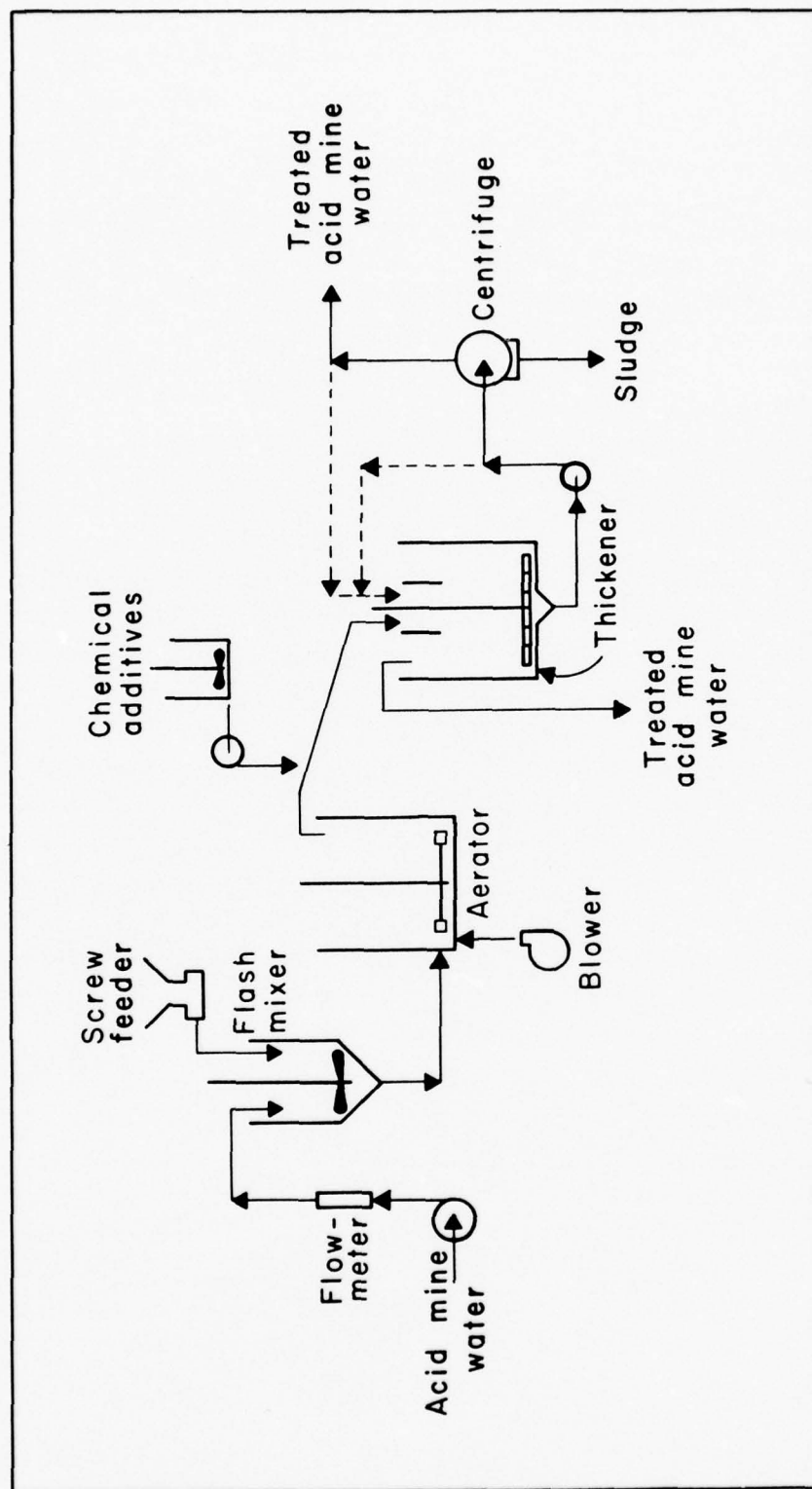


FIGURE 1.- Schematic Diagram of the Operation Yellowboy Process for the Treatment of Acid Mine Water.

TABLE 3. - Preliminary capital investment-operating costs for acid mine water treatment using Operation Yellowboy 1/

Item	Marianna #58		Little Scrubgrass		Young and Son		Morea Strip Pit		Loomis #4 Shaft		Warwick	
	Raw	Treated	Raw	Treated	Raw	Treated	Raw	Treated	Raw	Treated	Raw	Treated
Flow rate - MGD.....	0.240	7.6	4.15	---	0.180	7.1	4.00	5.76	3.20	7.4	2.78	0.60
pH.....	2.64	5.8	3.65	---	2.60	2.4	3.20	6.5	3.20	6.4	712.00	7.57
Total iron - ppm.....	815.00	---	1.30	---	225.00	---	5.80	---	360.00	---	2.60	---
Sulfate - ppm as SO ₄	10,000.00	6,180.0	301.00	---	1,360.00	1,530.0	290.00	370.0	3,430.00	3,240.0	5,656.00	3,740.00
Dissolved solids - ppm.....	18,300.00	12,200.0	-----	---	1,920.00	2,040.0	560.00	600.0	6,100.00	5,500.0	9,080.00	5,830.00
Estimated construction costs of required facilities.....	\$347,200.00		\$9,850.00		\$229,900.00		\$657,400.00		\$1,094,000.00		\$282,700.00	
Fixed costs attributable to construction costs.....	2/\$25,550.00		4/\$2,275.00		2/\$16,900.00		2/\$46,371.00		2/\$80,500.00		2/\$22,000.00	
Operating and administrative costs												
Supervision and labor.....	36,500.00		730.00		20,000.00		42,500.00		108,000.00		43,000.00	
Power.....	4,700.00		7,045.00		3,200.00		8,700.00		100,000.00		15,000.00	
Chemicals (lime).....	22,000.00		87.00		2,300.00		20,000.00		152,000.00		29,000.00	
Maintenance, repairs, miscellaneous and contingencies.....	6,500.00		99.00		5,000.00		7,000.00		35,000.00		8,500.00	
Total.....	\$69,700.00		\$7,961.00		\$30,500.00		\$78,200.00		\$395,000.00		\$95,500.00	
Total annual costs.....	2/\$95,250.00		2/\$10,236.00		2/\$47,400.00		2/\$126,571.00		2/\$475,500.00		2/\$117,500.00	
Total operating costs per 1,000 gal. of acid mine drainage.....	\$1.09		\$0.007		\$0.721		\$0.087		\$0.226		\$0.537	
Sludge - dry, tons per day ^{6/} ... CaO, tons per day.....	12.50 2.08		----- -----		0.69 0.31		2.17 2.23		21.6 10.0		16.5 NA	

1/ All data from report by Dorr-Oliver Inc., titled, "Operation Yellowboy" to the Pennsylvania Coal Research Board, The Department of Mines and Mineral Industries, Harrisburg, Pa., June 1966.

2/ 20 year amortization at 4% interest.

3/ Operating 365 days per year.

4/ 5 year amortization at 5% interest.

5/ Based on 1 man - 1/2 day per week for high flow and 1/2 day every other week for low flow.

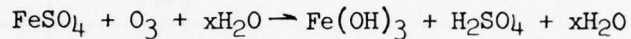
6/ Sludge resulting from acid mine drainage oxidation, neutralization, precipitation.

Coal Industry Research and Development

The operating coal companies are conducting developmental research on a variety of techniques for neutralization of their acid mine water. These techniques include not only neutralization, but impoundment for oxidation and settling in large holding basins. Other operating coal companies are blending their acid waters with alkali waters to comply with Sanitary Water Board regulations.

Ozone Oxidation

Ozone oxidation is a variation of air oxidation (aeration) presently being investigated and used by the coal industry. Ozone (O_3), as compared to air, is a powerful oxidizer and its effect on the rate of reaction of ferrous ion to ferric is a function of concentration, temperature, pH, and contact time. The overall reaction of ferrous iron with ozone, in acid solutions, accompanied by hydrolysis is:



The unit operations involved in the process consist of an ozonator with an air feed. During operation, a series of corona discharges within the ozonator converts the oxygen in the air to ozone (O_3). The unit, being self contained, meters the ozone (O_3) - air mixture into an application tank containing the acid mine water. The reaction in the tank is quite fast and the ferrous sulfate is converted to the ferric sulfate. Simultaneously hydrolysis takes place producing a solution containing ferric hydroxide and sulfuric acid. Additional equipment required for the process would consist of a neutralization tank, slurry thickener, and a bowl centrifuge for dewatering the slurry for subsequent disposal. However, these latter items of equipment and their cost have not been reported in the literature.

Simpson and Rozelle (18) investigated the ozone reaction mechanisms for the oxidation of ferrous- to ferric ion. The results of bench-scale investigations on ozone oxidation of ferrous iron, using synthetic and actual solutions of acid mine drainage, indicate that the reaction rate of Fe^{++} in the samples with xO_3 was independent of the concentration of Fe^{++} and temperature and dependent upon the rate of ozone added to the solution. The oxidation ratio of equivalent iron (Fe^{++}) to equivalent ozone (O_3) was found to be slightly less than one. Additional reaction mechanism studies were conducted on synthetic solutions containing small amounts of manganese. The rates of reaction with these synthetic solutions appeared to be slightly higher. The effect of manganese on the oxygen-ferrous iron reaction require further studies at low pH values.

The engineering and economic evaluation of the ozone process indicate that a large scale processing plant would be costly. Preliminary cost figures were obtained, by Wilkes College from consultants

and equipment suppliers, for a small scale pilot plant. The pilot plant has been designed to treat 72,000 gallons per day of acid mine water (table 4).

TABLE 4. - Major items of capital equipment for the ozone process (18)

Ozonator, Welsbach, 58.1 pounds per day air feed.....	\$28,625.00
Tank, application, SS or PVC.....	5,725.00
Meter, ozone, Welsbach.....	675.00
Recorder.....	550.00
Total.....	\$35,575.00

This tabulated equipment are only major items of capital equipment and they do not constitute a true and realistic capital investment cost for the pilot plant.

The electric power required for treating 72,000 gallons per day of acid mine water containing 220 ppm of ferrous ion with ozone has been estimated at 468 kwh per day. Assuming an ozone efficiency of 81 percent and electricity at \$0.01 per kwh, the operating cost for treating 1,000 gallons of acid mine water is about \$0.07 per 1,000 gallons.

Flash Distillation

Flash distillation is a vaporization and condensation process. The feed, in the liquid state, is heated to the vaporization point in an enclosed chamber and subsequently flashed, in a series of chambers or columns, operated at successively lower pressures and temperatures (fig. 2). The basic process has been utilized for years by the chemical industry for the processing of petroleum, organic chemicals, and inorganic chemicals. The principal items of equipment include evaporators, de-aerators, air ejectors, heat exchangers, pumps, air compressors, and steam generating systems.

The process, within the last 5 years, has been investigated, evaluated, and used for processing saline and brackish waters for producing of potable water for domestic use. Within the last few years, the process has been considered as a method for the treatment of acid mine waters for abatement of stream pollution (11, 17, 21).

Industry Sponsored Research and Development

Westinghouse Electric Corp. (21), under a contract with the Coal Research Board, Commonwealth of Pennsylvania, evaluated the flash distillation process for treating of acid mine water. Preliminary tests were made on a small scale pilot plant to determine the optimum operating

conditions and to assess the engineering and economics of the process as applied to acid mine water. The data obtained from these tests were used to design a 5 million gallon per day plant. Capital investment and operating costs were estimated for the 5 million gallon per day plant based on the data from the pilot plant operation (tables 5 and 6).

The capital investment cost estimated by Westinghouse is presented in table 5.

TABLE 5. - Capital cost summary for a 5 million gallon per day flash distillation acid mine drainage treatment plant (21)

Evaporator.....	\$5,788,794
Boiler and stack.....	1,246,000
Site development.....	81,190
Concrete work.....	340,400
Operations building.....	56,580
Intake screening.....	<u>25,070</u>
Total price of plant....	\$7,538,034

The estimated operating cost for flash distillation is \$0.9536 per 1,000 gallons of feed. In addition, solids disposal costs, estimated to be from \$0.1207 to \$0.1578 per 1,000 gallons must be included in the operating cost. Therefore, the total estimated operating costs will range from \$1.07 to \$1.11 per 1,000 gallons of feed.

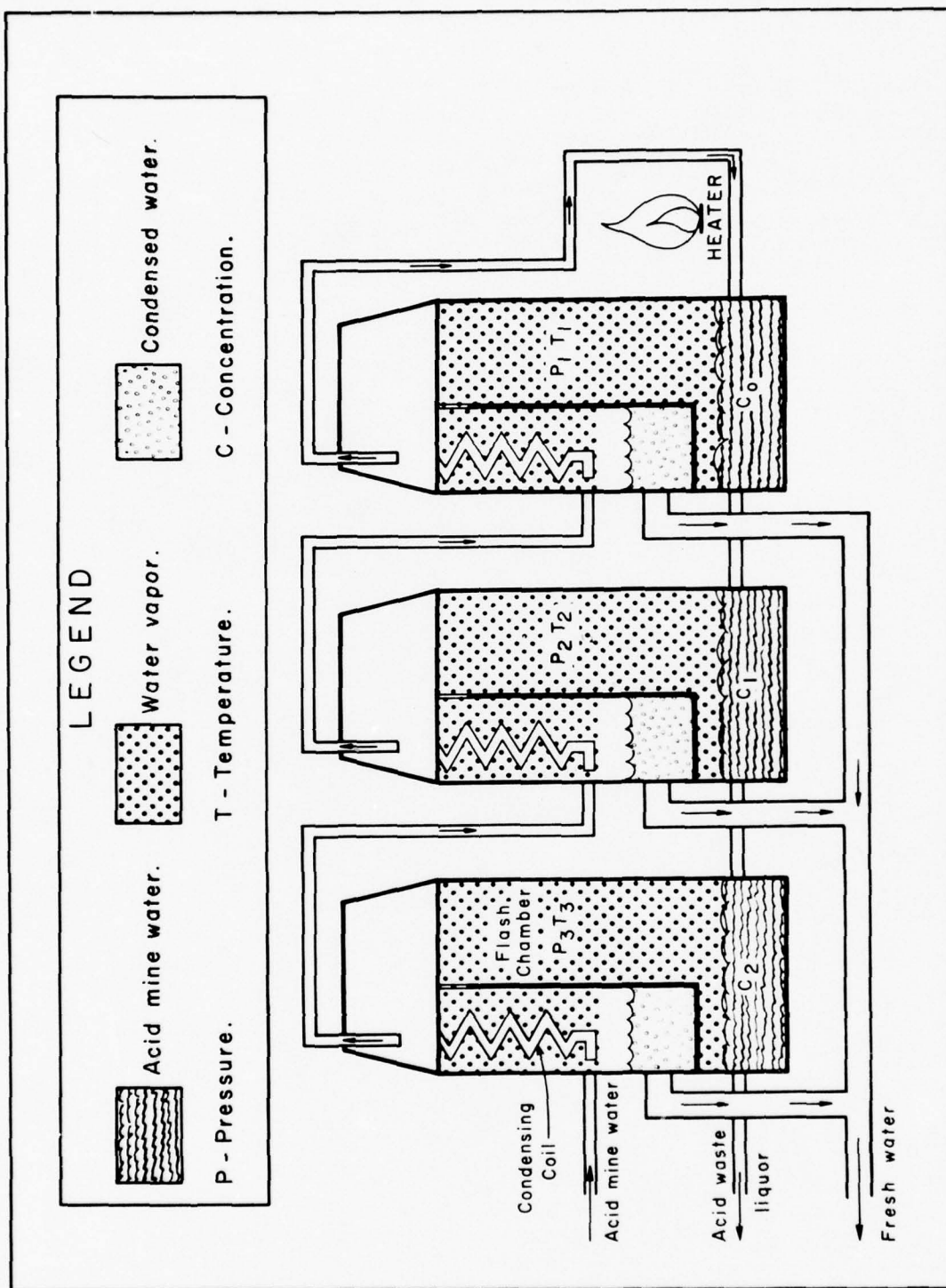


FIGURE 2. - Schematic Diagram of the Flash Distillation Process .

TABLE 6. - Operating cost for a 5 million gallon per day flash distillation acid mine drainage treatment plant (21)

Item	How defined ^{1/}	¢/1,000 gal.
Amortization.....	10.7%	46.00
Evaporator steam.....	15¢/10 ⁶ BTU	21.34
Ejector steam.....	15¢/10 ⁶ BTU	.16
Final crystallizer steam...	15¢/10 ⁶ BTU	.727
Electric power for acid mine drainage plant.....	0.6¢/KWH	6.457
Maintenance.....	2%	8.61
(Material and labor)		
Operating labor.....	9 men and one supv.	3.52
Payroll extras.....	15% total labor	.528
General overhead and administration.....	30% payroll	3.800
Power for boiler (coal pulverizers, fans, etc.)..	0.6¢/KWH	<u>4.320</u>
Total cost/10 ³ gallon...		95.46

^{1/} BASIS: 350 day per year operation, 20 year amortization, 6 percent interest, 2 percent insurance.

In assessing the flash distillation process, the quantity and quality of the feed in gallons per minute flow rate, the iron content, the sulfate content, and the total dissolved solids must be determined before the plant can be designed. The presence of these solutes in the water elevates the boiling point which results in foaming within the column, solids carryover, alkali sulfates, and carbonate scale and sludge deposits. The type of water will dictate the treatment required to solve a particular water control problem.

In addition, due to the nature of the mixed sulfate wastes from any acid mine drainage plant, it appears that the possible sale of the sulfate waste is not economically feasible to justify any additional plant processing.

Government Sponsored Research and Development

The Office of Saline Water in cooperation with the Bureau of Mines made an assessment of the multiple flash distillation as a means of controlling stream pollution by acid mine drainage (table 21) (17).

Reverse Osmosis

Reverse osmosis, as applied to acid mine waters, is the diffusion of acidic water through a semipermeable membrane so as to concentrate the iron salts and produce a potable water. High operating pressures, which are above the osmotic pressure, are required for the unit operation (fig. 3).

The basic process consists of a pressure vessel containing the membrane modular units, and a positive displacement pump. Auxiliary equipment consists of pretreatment facilities, instrumentation, pressure controllers and gauges, piping, motor, and pump controllers for product water and effluent discharge. The feed stream enters the top of the pressure vessel and flows across the membrane surfaces in series. Product water is discharged through the central shaft, and the concentrated salt solution is discharged at the bottom of the vessel.

In the design of equipment for treating water by reverse osmosis, various membrane support configurations have been investigated. These configurations of modular design, consist of the plate and frame, the tubular, and the spiral wound membrane units. The plate and frame appears to be the more promising due to the high pressures encountered and the relative ease for modular construction. The membrane is attached to a porous plate which equalizes the pressure on both sides of the membrane and permits operating at higher pressures (7, 16-17).

Government Sponsored Research and Development

Spiral Wound Type Membrane Modular Reverse Osmosis Unit

During 1965, General Atomic Division of General Dynamics conducted field tests on a reverse osmosis unit using two acid mine water feeds obtained from mines near Kittanning, Pa. The project was sponsored by the Office of Saline Water in cooperation with the Bureau of Mines(16) and its purpose and objectives were:

1. To determine whether reverse osmosis could operate satisfactorily using acid mine waters.
2. The degree to which acid mine water could be concentrated without precipitation occurring within the membrane.
3. The effectiveness of membrane pretreatment.
4. The relative merits of high flux low selectivity membranes.
5. The optimum flow path of feed through the modules.
6. The efficiency of operations with variable flow conditions.

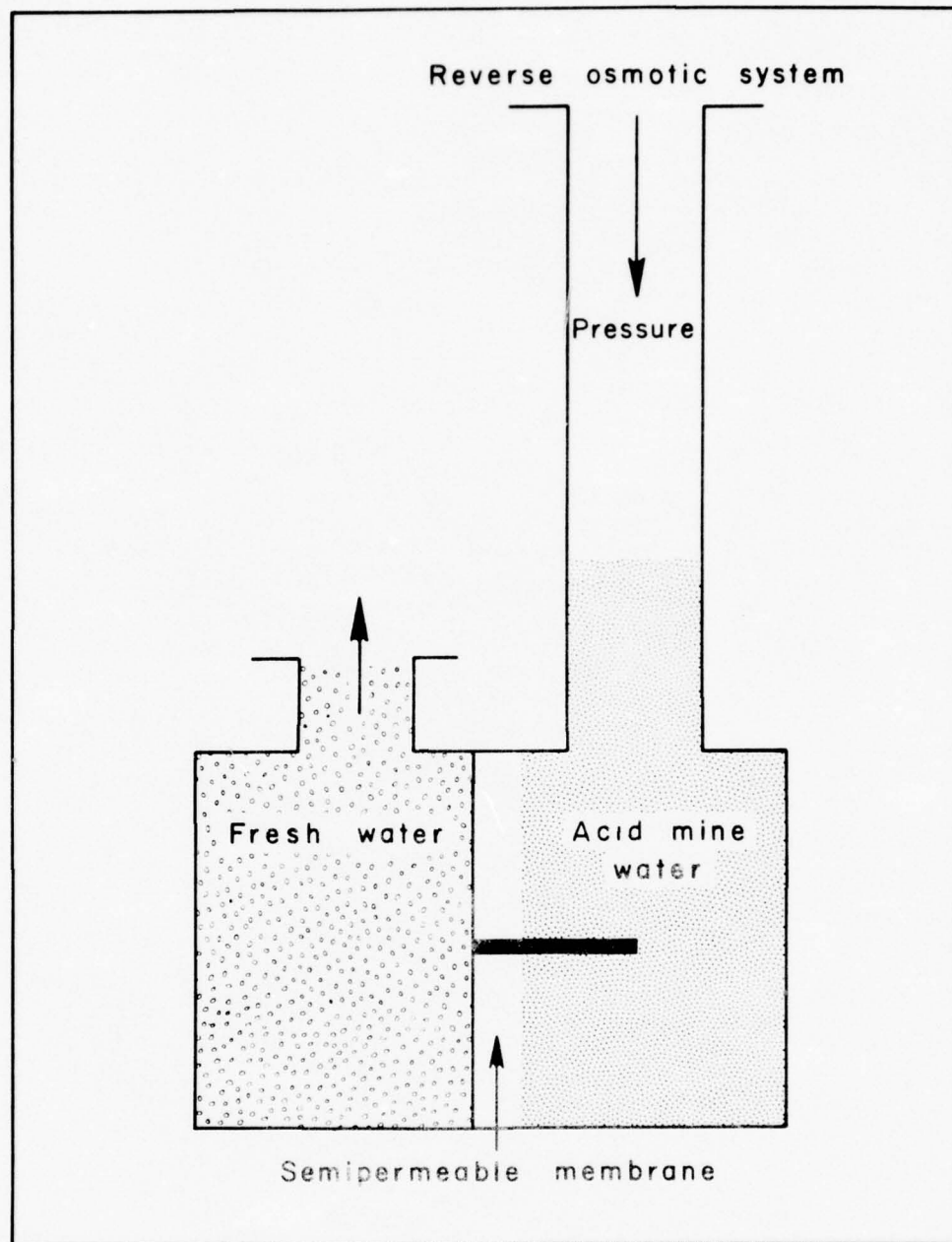


FIGURE 3.- Schematic Diagram of the Reverse Osmosis Process.

The results of these Kittanning, Pa., tests indicate that reverse osmosis can be effectively used in treating acid mine water (16-17). The product water was potable. The flow of water through the process remained constant. The acid concentration in the water was sufficient to maintain the solubility of the iron, calcium, and other alkali compounds. However, the problem of sludge disposal still exists and must be resolved. In addition, further research is required for refining the overall process.

The cost evaluation of the process by General Dynamics indicates that the process is technically feasible for the treatment of acid mine water. The capital investment cost ranges from \$250,000 (100,000 gallon per day plant) to \$1,407,000 (1 mgpd plant) (table 21) (17). The operating costs range from \$2.57 to \$1.09 per 1,000 gallons, respectively, of treated water of potable quality.

Plate and Frame Type Membrane Modular Reverse Osmosis Unit

Aerogel General Corporation has investigated the reverse osmosis process for the Office of Saline Water. Their research and development efforts were directed mainly to the production of potable water from saline and brackish water. However, the utilization of their process and cost data are applicable to the treatment of acid mine water (tables 7-9) (7).

The heart of the process is the membrane, a cellulose acetate film, which is the most suitable material being used in modular units today. The membrane is very thin and must withstand the pressure required for the process to work. Because of these high pressures--40 psi to 1,500 psi--a disc type multiple plate cell module has been developed. The membrane for each disc is supported by a porous plate between the membranes. This type of module appears far superior to the spiral wound tubular module types of membrane.

The selectivity of reverse osmosis process is 95 to 99 percent for common salt and 99 to 99.9 percent for calcium sulfate. The flux or diffusion rate through the membrane, total dissolved solids content from 2 to 10,000 ppm, range from 50 to 30 gallons per square foot per day (7).

TABLE 7. - The operating parameters for a 1 million gallon per day plant (7)

1. Total dissolved solids.....	1,500 ppm
2. Flux average.....	40 gpd
3. Water recovery.....	80 percent
4. Reject stream.....	6,500 ppm
5. Membrane life.....	1 year

TABLE 8. - Capital investment cost for a 1/4 million
gallon per day plant (7) *

Reverse osmosis cells.....	\$124,000.00
Filters.....	35,000.00
Pumps.....	52,000.00
Aerator.....	10,000.00
Total installed cost.....	\$221,000.00 **
Erection and assembly.....	66,000.00
Instrumentation.....	9,000.00
	<u>\$ 75,000.00</u>

* Comparable data for a million gallon per day plant are not available.

** Major items of equipment.

The total capital investment which includes engineering, water supply, contingencies, and other facets of plant investment would be approximately \$440,000.

TABLE 9. - The operating cost for a 1 million
gallon per day plant (7)

Item	\$/1,000 gal.
Electric power (0.007/KWH).....	\$0.068
Raw materials - membranes.....	.008
Supplies.....	.006
Operating and maintenance labor...	.060
Payroll extras.....	.008
Overhead.....	.022
Amortization.....	.095
Taxes and insurance.....	.025
Interest on working capital.....	.002
Total operating cost.....	<u>\$0.294</u>

Ion Exchange Process

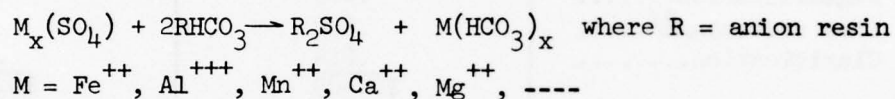
The use of ion exchange as a means for treating acid mine water has been and continues to be investigated and evaluated by research organizations, coal companies, universities, and resin manufacturers.

The basic process for the treatment of acid mine water by ion exchange (deionization) consists of the reaction of metal salts and hydroxides in water with specific anionic and cationic resins. Modifications to the basic unit operation are required in order to make the process feasible on an engineering and economic basis. These modifications take into account the quality of the acid mine water, specific resins, quantity of resin, regeneration and replacement of resins, chemical costs, and the practical life of an ion exchange process (fig. 4).

Industry Sponsored Research and Development

The Desal Process (6, 15, 17), developed by Rohm and Haas Company, is an ion exchange process applicable to acid mine water. The process uses a weak base anion resin which is operated in the bicarbonate cycle. The process takes advantage of the fact that metal sulfates represent almost the entire soluble anion content of typical acid mine water. These soluble metal sulfates are converted to bicarbonates which are by aeration, precipitated out of solution as insoluble hydrous oxides.

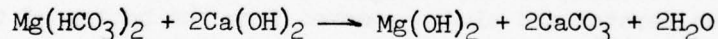
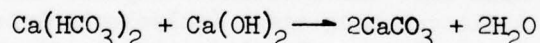
The general mechanism of the ion exchange process is as follows:



The unit operations involved in the process consist of carbonation of the anion resin, aeration, and alkalation of resin. The products from the aeration step are further treated by lime softening and clarification operations with the end product being processed water and sludge. The clarification and sedimentation rates are significantly improved with the use of an anionic polyelectrolyte (flocculent).

Comparison of ion exchange resins and lime neutralization sedimentation data, as reported by Rohm and Haas, indicate final sludge volumes to be less than 25 percent of lime sludge volumes.

Lime treatment of the aeration waters are given by the following equation:



As in other acid mine drainage processes, the problem exists of the disposal of sludge. It has been demonstrated, on laboratory scale, that the volume of sludge produced by the ion exchange process is substantially less than that produced in lime neutralization process.

Regeneration of the ion exchange resin is accomplished by passing ammonium hydroxide through the resin. Ammonium sulfate is formed as a byproduct to the reaction.

Data on the capital investment cost of the Desal Process are presently not available. Operating costs for the Desal Process for treatment of acid mine water, based on Amberlite IRA-68^{3/}, calculated for 100,000 gpd and 1,000,000 gpd plants are \$0.489/1,000 gal. and \$0.429/1,000 gal., respectively. The costs for each of the unit operations are listed in table 10.

TABLE 10. - Operating cost estimate for ion exchange process for treatment of acid mine water

Item	Dollars per 1,000 gallons	
	100,000 gal/day	1 mgpd
Alkalization.....	0.285	0.246
Carbonation ^{1/}149	.134
Degasification.....	.009	.003
Lime softening ^{2/}032	.032
Clarification.....	.014	.014
	<u>\$0.489</u>	<u>\$0.429</u>

1/ Includes CO₂ make-up.

2/ Chemicals only, does not include equipment.

In preparing these estimates, the acid mine water was assumed to have a sulfate content of 3,000 ppm (as CaCO₃) and an alkalization capacity of 75 pounds per cubic feet (as CaCO₃). Lime consumption was based on the assumption that 15 percent of the influent sulfate would remain in solution after aeration and represented an equivalent amount used during lime softening operations.

The Elpo Process (3), which appears to be a variation of the Desal Process operates on bicarbonate-lime cycle. The one variation is the design of the aeration unit which enables complete and rapid mixing within the unit. A flocculating agent (polyelectrolyte) is also used for rapid settling of the sludge. Treated water is discharged at the top of the aerator and sludge removed from the bottom of the unit by use of a specially designed solids removal mechanism.

The complete details of the process are not available. However, cost data for major items of equipment are estimated to be about \$125,000 and with site selection, structure design and erection, start up, and other incidental costs, this proposed plant may cost in

3/ Reference to specific brands is made for identification only and does not imply endorsement by the Bureau of Mines.

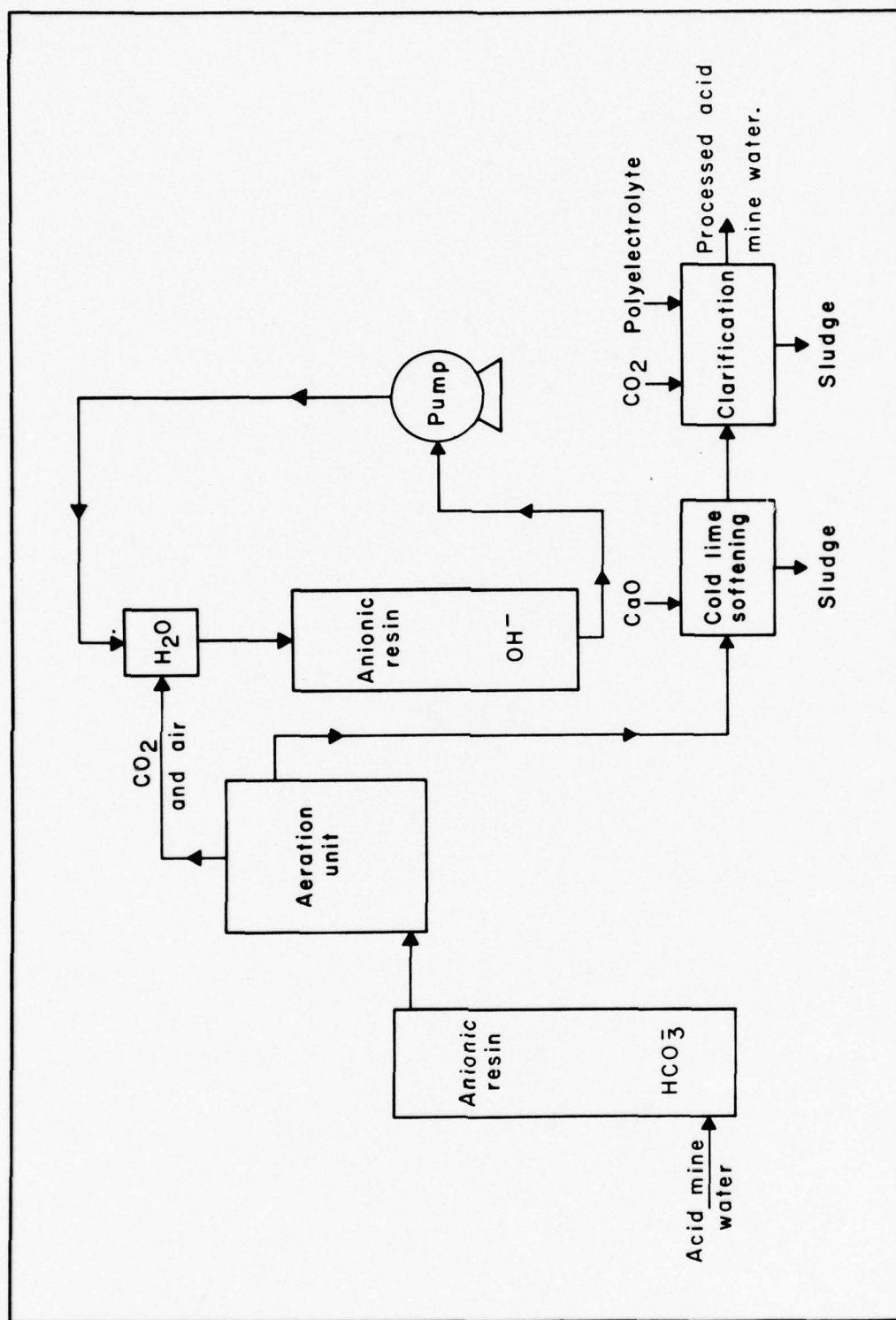


FIGURE 4.-Schematic Diagram of the Ion Exchange Process for the Treatment of Acid Mine Water With Carbon Dioxide Recovery. (15).

the range of \$300,000 to \$350,000. These costs are for a plant capable of treating 2 million gallons per day of acid mine water. Costs for operations (chemicals only) are reported to be less than \$0.07/1,000 gal.

Deep Well Injection

Deep well injection for the disposal of brine was developed by the petroleum industry in the early 1930's. During the last decade the chemical, pharmaceutical, paper, steel (9), and nuclear process industries have utilized this method for the disposal of liquid wastes and plant effluents. These same techniques have been investigated as a means of disposal of acid mine water (14, 20).

In assessing the practicability of this mode of disposal, the geological structure and formation of the strata must be known in the area where the disposal well is to be located. The data required in assessing a specific location are the permeability, porosity, and extent of the receiving formation. Disposal wells drilled, to date, by the chemical and steel industry, range in depth from 300 feet to 12,000 feet below the surface and utilize disposal formations of unconsolidated sand, sandstone, limestone, and fractured gneiss (4, 14).

The schematic flow diagram of the process is given in figure 5. Clarified water enters the disposal plant piping system. This water is used to continuously flush the well annulus and to displace acid mine water from the equipment and well bore for service and maintenance work. A heat exchanger is provided to maintain system temperature and to prevent precipitation of the dissolved solids in the acid mine water. The annulus water passes through a sand filter to the high pressure pumps and into the well.

Acid mine water from the impoundment basins or holding reservoirs enters the plant piping system. Booster pumps provide the pressure required to operate the acid mine water filter. The filtered acid mine drainage enters a high pressure pump and discharges through a shock suppressor to the well head and into the injection tubing (4). The acidic wastes are pumped down the well and out into the disposal formation. The acid waste advances into the strata essentially as a disc of ever-increasing size, whose center is the well bore and whose thickness is dependent upon the thickness of the permeable zones in the formation.

Three types of wells should be evaluated for potential use in the disposal of acid mine water. They are depleted gas and oil wells, dry holes, and wells drilled specifically for disposal of acid mine water. Utilizing the driller log history of these types of wells could provide the required data needed to ascertain permeability, porosity, and uniformity of porosity. The porosity should be high enough to provide disposal capacity, permeability, and insure lateral movement within the strata.

The drilling, casing, and testing of a 2,000 feet deep disposal well costs approximately \$70,000 (4, 14, 20). Additional costs to be included with this initial cost would be the cost of well fracturing for altering or increasing strata porosity. Above ground facilities required are solids filtering, storage, and high pressure positive displacement pumps.

Tentative conclusions made by Vonder Linden and Stefanko (20) was that limited quantity of acid mine water could be pumped into subsurface strata for permanent disposal.

Industry Practice For Disposal of Acidic Wastes

Jones and Laughlin Steel Corp. (9) have been using deep well disposal of spent pickle liquor wastes as a means of abating water pollution problems. Many problems have been encountered in this type of disposal of acidic wastes, but the company is of the opinion that the program will prove satisfactory. Although actual cost data for disposal of their waste liquor are not known at this time, they feel that the cost will be lower than by truck disposal.

Inland Steel Company (13), Indiana Harbor works, has allocated \$2.6 million for a 4,300-foot deep well for disposal of spent acid. The disposal system will consist of three sets of pumps and four collection tanks at the mills, three pipelines under the plant, and two storage tanks, filters, and an injection pump at the well. Initially, the well will dispose of 137,000 gallons of waste pickle liquor per day. The wells disposal capacity is estimated at up to 432,000 gallons per day. The data on capital investment and operating costs are not available.

Government Survey on Industrial Waste Disposal

Donaldson (4) made a study on subsurface disposal of industrial wastes in the United States. Industrial wastes are being disposed of by injection into more than 30 wells ranging in depth from 300 to 12,000 feet into formations varying in age from Precambrian to Recent. The reported cost of deep well disposal systems ranged from \$30,000 to \$1,400,000. He concluded that subsurface injection is the most economical solution for many difficult disposal problems. However, it is not the solution to every waste problem.

An estimated capital investment cost for an injection well under favorable conditions, and with the basic well specification are given in tables 11 and 12 (4).

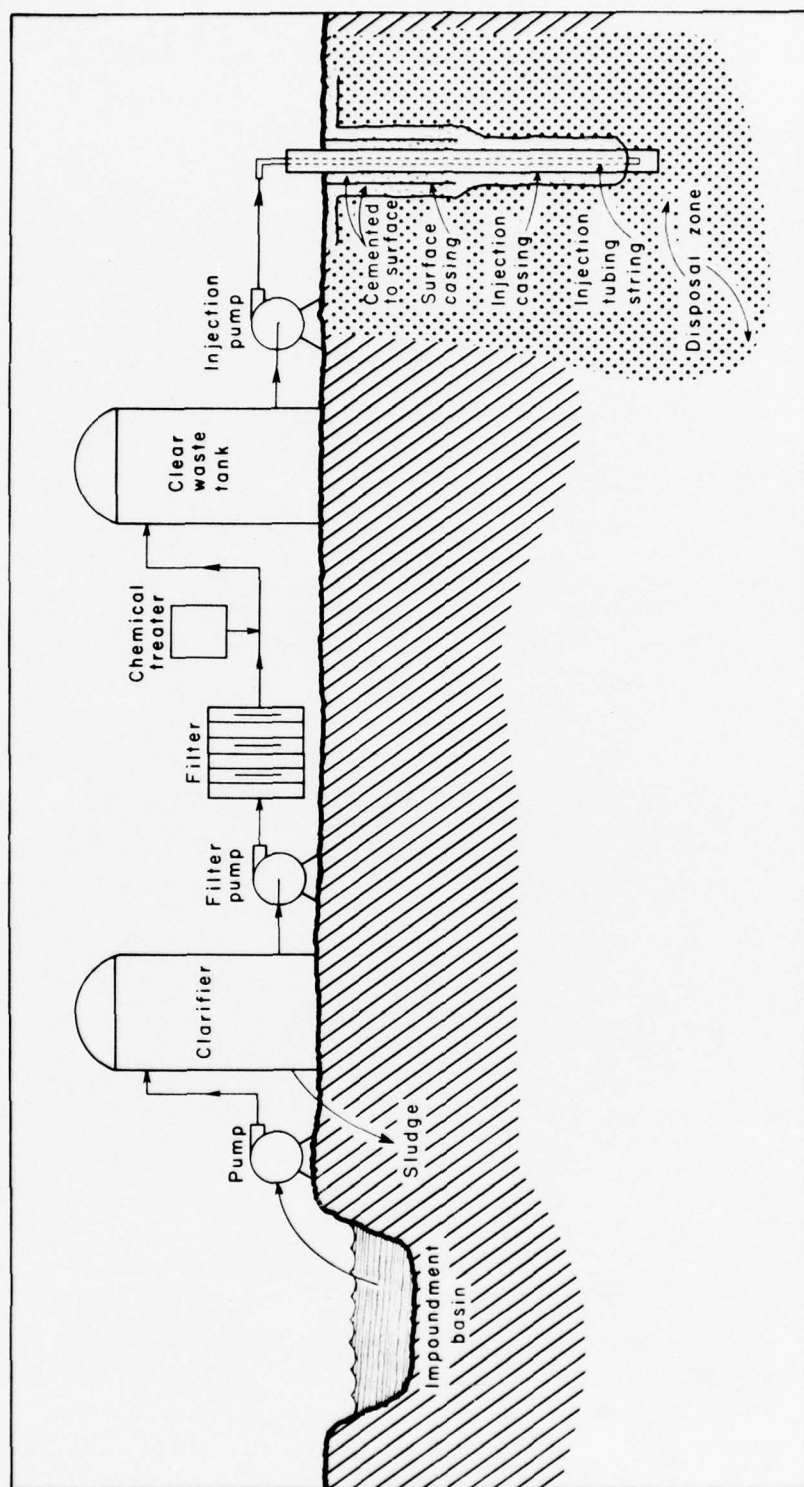


FIGURE 5. - Schematic Diagram of a Subsurface Acid Waste Disposal System.

TABLE 11. - Well specifications

Depth of well.....	3,000 feet
Surface casing, 200 feet.....	10-1/2" OD
Injection casing, 3,000 feet.....	7" OD
Tubing, 3,000 feet.....	2-3/8" OD
Completion method - Casing perforations at disposal zone.	

TABLE 12. - Capital investment cost^{1/}

Drilling costs: drilling of hole, mud, coring, logging, stem test, well stimulation.....	\$ 30,000.00
Materials: surface and injection casing, tubing, and well head.....	20,000.00
Testing: analyses of cores, wastes, etc.	5,000.00
Engineering and consulting.....	15,000.00
Surface equipment.....	125,000.00
Monitor well-1,000 feet deep.....	5,000.00
Total cost.....	<u>\$200,000.00</u>

^{1/} No general operating costs were given for this typical disposal system.

RECLAMATION OF COAL STRIP MINED LANDS

Under Section 205(a) of Public Law 89-4, the Appalachian Regional Development Act of 1965, the Secretary of the Interior is authorized to make financial contributions to States for reclamation of strip mined lands (19).

Basic Reclamation

Basic reclamation, for the purpose of this report, may be defined as water quality control through proper mine water drainage, the covering over of toxic materials, and revegetation of pit and spoil bank areas. This does not imply the restoration of the terrain to its original contour but is concerned primarily with the control of acid pollution and siltation of streams and rivers.

Table 13 presents the estimated cost for basic reclamation and includes grading, drainage, and vegetation.

Erosion of spoil banks and stream sedimentation can be controlled by proper drainage which may require only grading and revegetation, and in some cases, checkdams, settling ponds, stone rubble, culverts, or piping.

Scope of the Problem

Approximately 800,000 acres of land have been disturbed by strip coal mining in Appalachia (19). Bituminous coal mining accounts for 92-1/2 percent and anthracite accounts for 7-1/2 percent of this acreage (table 14). Contour mining accounts for 74 percent of the area or 592,000 acres and 75 percent of the coal strip mined. Area mining accounts for 26 percent or 208,000 acres and 25 percent of the coal strip mined.

Coal strip mining is the removal of the earth and rock (overburden) cover from a coal seam or bed in order to permit the easy removal of the coal from the seam by use of conventional earth moving equipment. Area strip mining consists of digging a series of cuts to expose the coalbed. The overburden from each cut is placed into an area or cut from which coal has been removed and forms piles of material called spoil banks. The stripping procedure is continued until the entire coalbed has been removed, the boundary of the tract reached, or the ratio of the overburden to coal seam exceeds an economical feasibility limit.

Contour stripping consists of removing the overburden from the coal seam starting at an outcrop and proceeding around the hillside. After the uncovered coalbed is removed, successive cuts are made until the overburden becomes too great for the equipment or the ratio of overburden to coal becomes uneconomical.

The nature of the spoil type is determined by the combination of its acidity and texture (tables 15 and 16). Other environmental factors affect the choice of planting material. The climate and the amount of rainfall limits the species that will grow in any particular area. In addition, the topography of the spoil influences survival and growth through its effect on soil moisture, soil depth, light, temperature, erosion, and protection from the wind.

Cost of Reclamation

The costs of strip mine reclamation appear in two stages. Some are incurred after mining is completed; abandoned strip mine pits are of this type. Operating strip mine pits, due to mining regulations, incorporate costs of reclamation in their overall operating costs.

TABLE 13. - Estimated costs for basic reclamation of
Appalachian areas mined for coal (19)

	Cost per acre	Acres	Total cost ^{1/} (million dollars)
Grading:			
Contour Mining ^{2/}	200	180,000	41
Area mining ^{3/}	100	65,000	7
Drainage from bench.....	196	547,000	124
Vegetation.....	125	350,000	50
Bituminous total.....			222
Anthracite ^{4/}	500	50,000	<u>29</u>
Total cost.....			251

^{1/} Includes 15 percent for planning, engineering, and administrative costs.

^{2/} Includes backfilling necessary to cover the coal seam and other sources of toxic material and to cover the bench to a minimum depth of 3 feet. The establishment of drainage gradients on the contour bench is also included.

^{3/} Includes minimum grading necessary to provide access for planting and to control drainage from the area - not within the area. Excludes backfilling except that required to cover toxic materials.

^{4/} Because of extremely complicated problems in the anthracite region of Pennsylvania, a breakdown of cost components was not attempted.

TABLE 14. - Status of strip and surface mined coal
lands in Appalachia (as of Jan. 1, 1965,
in acres, as reported by State authorities)(19)

State	Unreclaimed	Partially reclaimed	Completely reclaimed	Total disturbed ^{1/}
Alabama.....	2,200	11,700	5,000	18,900
Georgia.....	-	75	225	300
Kentucky.....	31,487	4,439	12,363	48,289
Maryland.....	494	753	995	2,242
New York.....	-	-	-	-
North Carolina.....	-	-	-	-
Ohio.....	33,540	21,900	^{2/} 123,816	^{3/} 179,256
Pennsylvania.....				
Bituminous.....	158,500		83,600	242,100
Anthracite.....	^{4/} 50,000		<u>9,000</u>	<u>59,000</u>
Total Pennsylvania.	<u>4/</u> 208,500		<u>92,600</u>	<u>301,100</u>
South Carolina.....	-	-	-	-
Tennessee.....	25,387	275	1,098	26,760
Virginia.....	15,014	13,549	503	29,066
West Virginia.....	^{4/} 145,718		<u>46,320</u>	<u>5/</u> 192,038
Total.....	108,122	52,691		
	<u>4/</u> 354,218		282,920	797,951

^{1/} From inception of stripping to Jan. 1, 1965.

^{2/} Represents reclamation for period 1948-65.

^{3/} Represents disturbed acreage, 1914-65.

^{4/} No breakdown reported by State.

^{5/} Represents disturbed acreage to Jan. 1, 1965.

TABLE 15. - Acidity of strip-mined lands (12)

Class Number	Description	pH	Percent of area at this pH
1.	Toxic	≤ 4.0	More than 75
2.	Marginal	≤ 4.0	50 - 75
3.	Acid	$> 4.0 - 6.9 <$	50 - 75
4.	Calcareous	≥ 7.0	More than 50
5.	Mixed, too varied to be classified as any of the above.	-	-

TABLE 16. - Texture of strip-mined lands (12)

Group	Description of texture
A.	Chiefly sand, sandstone, or sandy shales
B.	Chiefly loam materials and silty shales
C.	Chiefly clay and clay shales

Information on the cost of strip mine reclamation and control of acid mine drainage is not widely applicable, because each mining system is unique in some respect. The available data are of limited value because usually there is no indication of what degree of reclamation has been done; for example, simple bulldozing of spoil against the high wall to the development of fields and forests. In addition, costs vary with the nature of the terrain, local employment, and ultimate use of the reclaimed land (table 17 and 18) (fig. 6).

Grading costs are reported to range from 4 cents per yard to 20 cents per yard of waste (19).

Estimates prepared by a special committee, appointed by the Secretary of Agriculture, reported that costs of restoring mined land to something like the original terrain forest cover would range from \$1,800 to \$3,000 per acre plus \$800 to \$1,500 per acre for land that was disturbed but not actually mined.

The problem of averaging reclamation costs is useful in determining order of magnitude cost figures. The most frequently cited cost figure is fifty (50) dollars per acre. This figure includes very little grading, some soil preparation, simple erosion control, and planting of tree seedlings.

The cost of revegetation or planting costs are more readily available. The cost of initial tree planting as reported range up to \$106 per acre. Forage and cereal costs average \$35 to \$40 per acre and soil testing and preparation may cost an additional \$30 to \$40 per acre. It is estimated that planting costs will range from \$30 per acre for spot planting to \$300 per acre where acid and toxic areas must be treated.

The results of an investigation made by the Federal Bureau of Mines on Demonstration and Evaluation of Five Methods of Secondary Backfilling of Strip-Mine Areas is presented in table 19. The costs reported range from \$912 to \$2,770 per acre. Methods A, B, and C, the spoil banks were regraded approximately to contour. Methods D and E, the highwalls were reduced by blasting techniques with bulldozing of spoil to cover the toxic or coal seam and level the contour of the bank. Grading costs, by bulldozer have been estimated at about \$200 per acre or about \$0.10 per yard.

DRAINAGE CONTROL METHODS

Measures used to control the acid mine water drainage are primarily ones that prevent water from entering the mine, either underground or strip. These measures are strictly physical diversion techniques.

The effectiveness of mine drainage control methods are in a sense unique to the specific coal mining operation. The basic principles involved with acid mine drainage, whether in strip or underground mines,

TABLE 17. - Cost, in 1964 of reclaiming land disturbed by stripping,
bituminous coal in Appalachia, by State (19) 1/

State	Reclaimed					
	Completely			Partially		
	Acres	Contract cost		Acres	Contract cost	
		Total	Average per acre		Total	Average per acre
Alabama.....	-----	-----	----	136	\$17,075	\$126
Georgia.....	-----	-----	----	-----	-----	-----
Kentucky.....	97	\$31,045	\$320	-----	-----	-----
Maryland.....	39	5,100	131	42	11,370	271
New York.....	-----	-----	----	-----	-----	-----
North Carolina	-----	-----	----	-----	-----	-----
Ohio.....	4,779	1,268,116	265	2,784	519,042	186
Pennsylvania..	3,815	1,378,770	361	1,282	375,465	293
South Carolina	-----	-----	----	-----	-----	-----
Tennessee.....	-----	-----	----	142	16,750	118
Virginia.....	-----	-----	----	-----	-----	-----
West Virginia.	422	77,188	183	1,519	137,616	91
Total....	9,152	2,760,219	302	5,905	1,077,318	182

1/ Information provided by industry to the Department of the Interior.

TABLE 18. - Approximate reclamation cost per ton of bituminous coal mined by stripping
in Appalachia, in 1960, by State (19)

State	Calculated production per acre mined*	Cost per ton at reclamation costs of -					
		\$300 per acre	\$400 per acre	\$500 per acre	\$600 per acre	\$700 per acre	\$800 per acre
Alabama.....	4,032	\$0.074	\$0.099	\$0.124	\$0.149	\$0.174	\$0.198
East Kentucky..	4,464	.067	.090	.112	.134	.157	.179
Maryland.....	6,192	.048	.065	.081	.097	.113	.129
Ohio.....	5,328	.056	.075	.094	.113	.131	.150
Pennsylvania...	4,608	.065	.087	.109	.130	.152	.174
Tennessee.....	4,176	.072	.096	.120	.144	.168	.192
Virginia.....	5,904	.051	.068	.085	.102	.119	.136
West Virginia..	7,056	.043	.057	.071	.085	.099	.113
Appalachian region...	5,184	.058	.077	.096	.116	.135	.154

* Based on specific gravity of 1.32=82.64 lb. per cu. ft., or 1,440 tons per acre-foot, at assumed 80 percent rate of recovery x the State average-thickness of seam (ft.) mined in 1960.

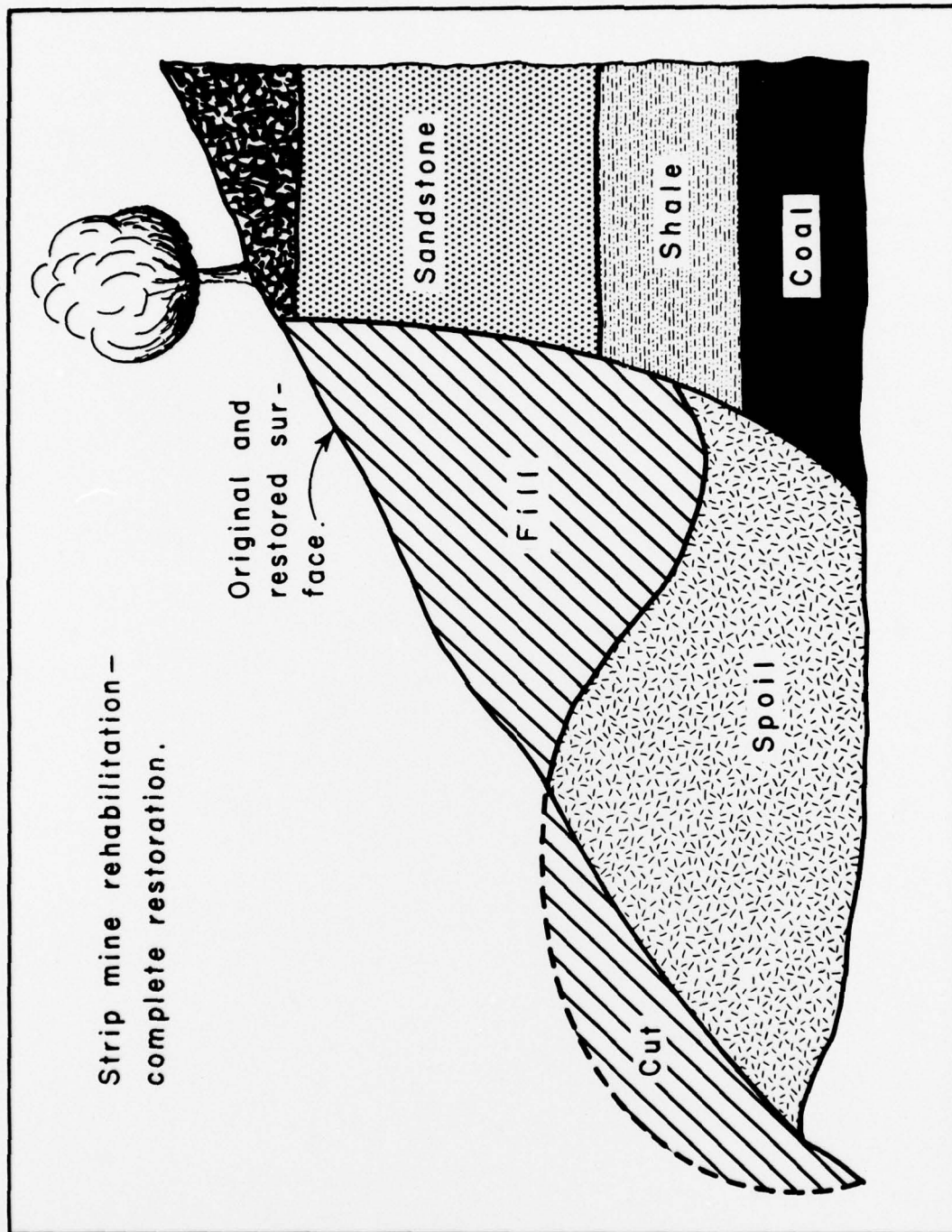


FIGURE 6. - Schematic Diagram Illustrating the Reclamation of a Strip Mine Area.

TABLE 19. - Summary of costs of five backfilling methods^{1/}

Item	Total hours	Total feet	Hour per foot	Cost per hour	Cost per linear foot of highwall	Cost per acre (approximate)
Method A: Bulldozers..	213	570	0.37	\$14.00	\$5.18	\$912
Method B:						
Labor.....	690	370	{ 1.86 .66 1.09 }	2.90	5.40	-----
Bulldozers.....	244			14.00	9.24	-----
Powersaws.....	404			1.00	1.09	-----
Total.....					15.73	2,770
Method C:						
Labor.....	540	630	{ .86 .63 .39 }	2.90	2.49	-----
Bulldozers.....	398			14.00	8.82	-----
Powersaws.....	246			1.00	.39	-----
Total.....					11.70	2,061
Method D:						
Labor.....	1,040	850	{ 1.22 .13 .59 .12 3/68.61 }	2.90	3.54	-----
Bulldozers.....	109			14.00	1.82	-----
Powersaws.....	500			1.00	.59	-----
Drill.....	101			22.00	2.64	-----
Explosive.....	2/58,320			4/.08	5.49	-----
Total.....					14.08	2,478
Method E:						
Labor.....	639	660	{ .97 .18 .35 .11 3/9.24 }	2.90	2.81	-----
Bulldozers.....	122			14.00	2.52	-----
Powersaws.....	232			1.00	.35	-----
Drill.....	75			22.00	2.42	-----
Explosive.....	2/6,100			4/.08	.74	-----
Total.....					8.84	1,556

^{1/} Source: Bureau of Mines Report of Investigation 6772.

^{2/} Pounds.

^{3/} Pounds per foot.
^{4/} Dollars per pound.

are the prevention or minimizing of water seepage into the mine, the removal of mine water as rapidly as possible, the segregation of sulfur bearing material, and the neutralization of acid pools (table 20).

In strip mines, drainage control can be accomplished by surface water diversion ditches along the high wall of the stripping operations. Ground water from springs and streams can likewise be diverted. Segregation of the overburden and sulfur bearing material is necessary for prevention of secondary formation of acid water and facilitates backfilling and contouring of the strip mine area. The reclamation of strip mine areas have the benefit that these measures help to protect the watershed, reduce acid water seepage, and siltation of receiving streams.

In underground mines, drainage control can be accomplished by constructing diversion ditches around openings, sealing streambeds at troublesome points, grouting underground areas to seal off stream channels, and constructing new stream channels if necessary. Flumes are used to conduct surface water across mining properties and dumping it into approved preselected drainage channels.

Mine Sealing

Underground mines can be closed by the construction of bulkheads or seals. These closures are built of stone, masonry, block, and compacted soil and clay. The design and placement of the seal in the bedrock should provide the required strength to assure the safety of the seals and bulkheads to withstand the water and ground pressure present. One or more of these closures may have to be incorporated in the seal and be provided with restricted water outlets with water traps (fig. 7). Grouting or rock bolting of the seals may have to be used to assure stability and to prevent leakage.

Reported cost data on mine sealing are given in table 20. The Department of Mines, West Virginia, estimates for 1966 range from \$850 to \$1,650 per seal. The Federal Water Pollution Control Administration reported estimates of \$600 to \$2,000 per seal. The estimated average being about \$1,300 per seal. The Bureau of Mines, estimates on sealing certain abandoned mine openings were about \$5,000 per seal. However, these estimated costs included extensive preconstruction work which was required before the seals could be installed.

Drainage Diversion and Impoundment

In strip mining operations, mine drainage control methods and costs are dependent upon the topography of the strip area. Drainage ditches may be required along the highwall of the strip area, as well as flumes along the bench, stream diversion, and construction of

TABLE 20. - Cost data for acid mine water drainage control measures^{1/}

Method	Unit	Cost, dollars	Comments
Mine sealing			
Wet and dry mine seals..	Per seal	850-2650	Department of Mines, W. Va.
Mine bulkheads.....	Per opening	1100	Active mine, Pa.
Average of 8092 seals...	Per opening	1070	Weighted average, using ENR Index
Mine sealing.....	Per seal	600-2000	FWPCA - average estimate-\$1,300
Mine sealing.....	Per seal	5000	U.S.B.M. figures
			Abandoned mine - extensive work required for preparing and making seal
Drainage diversion			
Pipe flume.....	Lin. ft.	6	Drainage from bench to stream
Ditch.....	Lin. ft.	0.04-0.40	Open ditch above high wall
Stream diversion	Lin. ft.	1.51	Soil Conservation Service estimate
Impoundments:			
Ponds - (5-30 acres)....	Surface acre	1000-500	Data from Pa. and W. Va. Larger the
Dams.....	Acre - feet	125-500	impoundment, smaller the cost
			Impoundment dams constructed at the end of last strip pit

^{1/} Handbook of Pollution Control Costs in Mine Drainage Management
U.S. Dept. of Interior - Federal Water Pollution Control Administration
December 1966, 54 pp.

impoundment basins for prevention of water contact with acid producing minerals. Table 20 presents the cost data of these methods of drainage control. Open pipe flumes have been estimated (table 20) to cost about \$6 per linear foot while open ditches along the highwall have been estimated to cost from \$0.04 to \$0.40 per linear foot of highwall. The cost of diverting streams has been estimated at \$1.51 per linear foot. Costs on construction of impoundment dams at the end of the last cut in strip operations have been estimated at \$125 to \$500 per acre foot.

Impoundment Basins

Impoundment, as the name implies, is the retaining of acid mine water in a confined basin. These are usually earthen basins which hold the acid mine water for some form of treatment, such as aeration and neutralization, prior to discharge into a receiving stream or controlled discharge flow into a receiving stream (fig. 8). The basins, normally two in series, can impound 2.5 to 5 million gallons per day and cover a surface area of 5 to 50 acres. Cost estimates on construction of the basin range from \$500 to \$1,000 per acre.

CONCLUSIONS

The status of process development for the control of acid mine water drainage pollution and for the reclamation of surface and strip mine areas is such that the technologic and cost data required for comparative engineering and economic evaluation of the various methods and techniques are not fully known or presently available.

Data on unit operations and processes have been obtained from bench-scale and semi-pilot plant operations and scaled-up by various investigators for the design of large scale plant operation (table 21). Data for strip mine reclamation were obtained from operating coal companies, universities, and government sponsored demonstration projects (19).

In general, the following comments can be made on the various methods for control of acid mine water pollution:

1. Neutralization of acid mine water is effective in the control of stream pollution. The problem of solid waste disposal and soluble salts in the effluent water requires additional investigation.
2. Operation Yellowboy, a more refined approach to neutralization, substantiates the necessity of prior assessment of the quality and quantity of acid mine water to be treated. These factors directly relate to the costs to be expected in treating the various types of acid mine water.

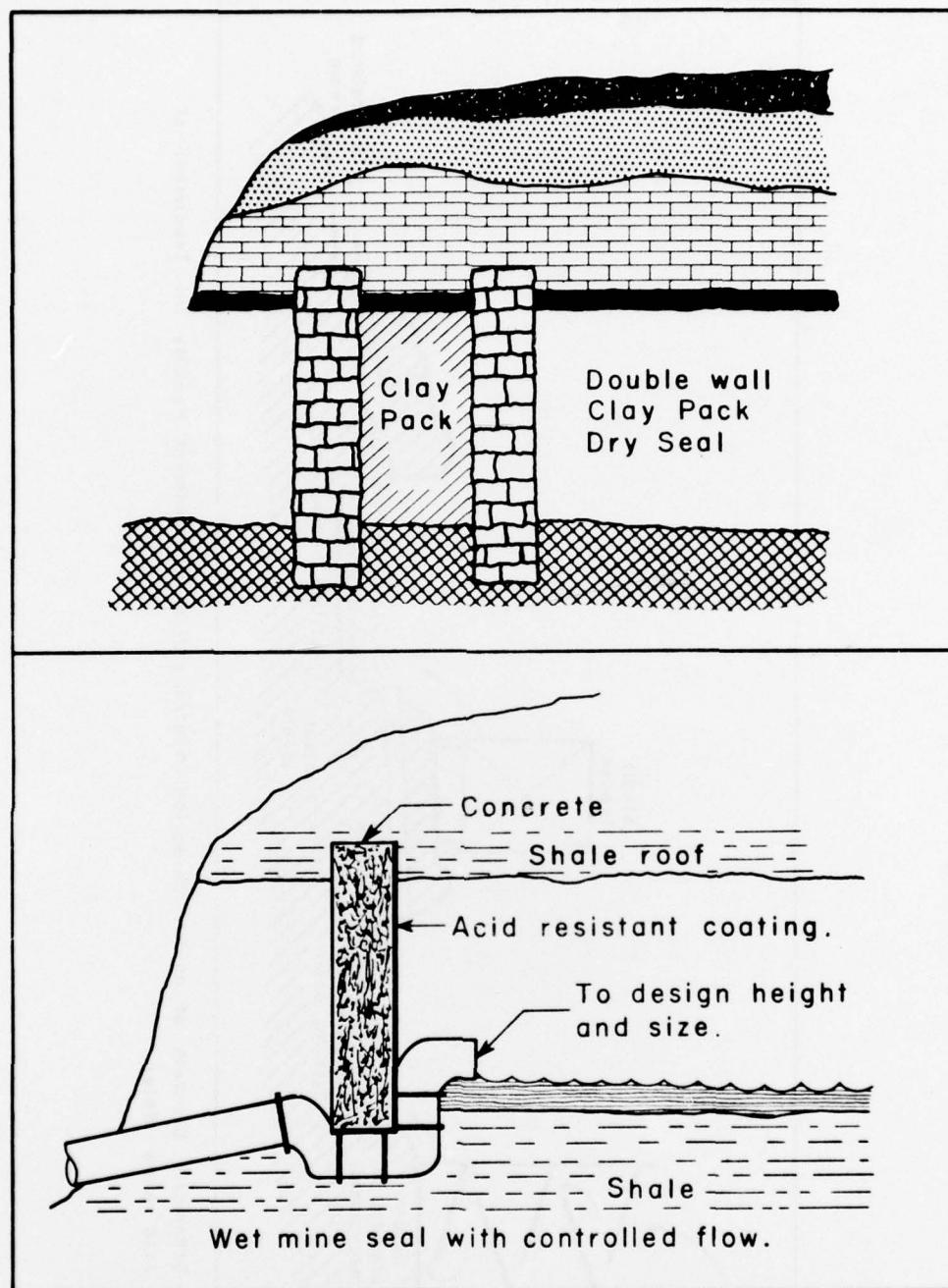


FIGURE 7.- Schematic Diagram of Mine Sealing Techniques for Control of Acid Mine Water Drainage.

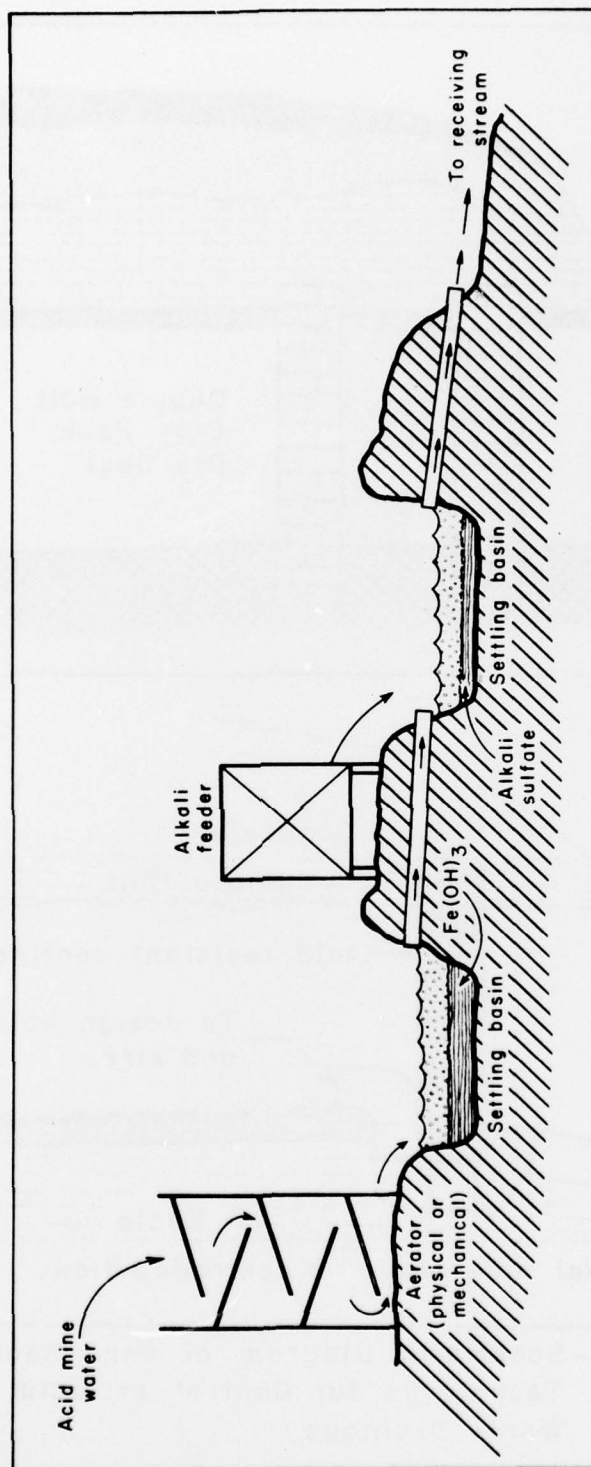


FIGURE 8.- Schematic Diagram of an Air Oxidation - Neutralization Impoundment Facility for Treatment of Acid Mine Water.

3. Ozone oxidation, although effective in the oxidation of ferrous to ferric hydroxide, contained in acid mine water, is presently in the research phase. On large scale treatment, the costs based on the evaluation of bench-scale reports, would be prohibitive. Additional research is required on the process for a more realistic evaluation.
4. The technology and economics of the evaporative process - flash distillation - are well known and used by the chemical industry. Its application to saline, brackish, and acid mine water have been proven and are on a sound basis for accurate evaluation. The process, to be economically practical, must be used where large volumes of water are available for processing.
5. The membrane process - reverse osmosis - are in the research and development stage. The economics and practicability are uncertain at the present time. Rapid strides have been made in the last few years for its application for processing saline, brackish, and acid mine waters. Additional areas of research and development required for the process are increase in flux rates, stability of the membrane, membrane configuration and modular design, and concentrated wastes disposal studies.
6. The technology and economics of the ion exchange processes for water treatment are also well known to the chemical industry. The process has undergone extensive changes during the last few years. Two of the processes presently being investigated for acid mine water treatment are the Desal and Elpo processes. The particular research and development has been in the area of anionic and cationic resins. In specific cases, cost and capacity data are available for these resins and the economics of ion exchange for treatment of brackish and acid mine water treatment can be determined with a high degree of accuracy.
7. Subsurface disposal of acid mine water via deep well injection, although technically feasible, is impractical as a method for control of acid mine water pollution. Cost data are generally available for well drilling and completion. The cost of above ground facilities are dependent upon strata formation, depth of well, and type of waste effluent, and injection pressures required for disposal.
8. Impoundment basins and lagoons, appear to be quite successful in the treatment of acid mine water. Coupled with aeration and neutralization facilities they offer a relatively inexpensive means for control of acid mine water drainage pollution.
9. Land, disturbed by strip mining of coal, can be reclaimed. The cost of reclamation is dependent upon the type and degree of reclamation and sometimes on final land utilization.

10. The reclamation of the strip mined land is an effective method for the control of acid pollution and siltation of our natural waterways. Where mine subsidence has disrupted normal drainage patterns, or where surface mining has broken through to underground workings, surface reclamation may serve to prevent water from entering underground channels, thereby reducing the formation of acid.
11. Some authorities claim that mine sealing can be an efficient and effective method for control of acid mine water pollution. Others disagree. Further experimentation is needed to clearly demonstrate the degree of the effectiveness of this method.

TABLE 21. - Summary of cost data on processes and unit operations for treatment of acid mine water ^{1/}

Type of process or operation	Capacity gallons per day	Capital investment (dollars)	Annual operating cost (dollars)	Treatment cost dollars per 1,000 gal.	Comments
Neutralization					
Limestone - pulv.....	500,000	-----	19,290.00	0.106	Data calculated on industry practice of using 7-1/2 lbs. hydrated lime per 1,000 gallons of typical acid coal mine water. Operating cost based on raw materials, labor, incidental costs. No attempt made to estimate capital investment cost of treatment facilities as these can be quite varied in nature of equipment, etc.
Lime - H ₂ CaO (pure).....	500,000	-----	24,065.00	0.132	
Calcium carbonate - air floated.....	500,000	-----	20,500.00	0.156	
Lime, hydrated.....	500,000	-----	29,240.00	0.160	
Ammonia, anhydrous.....	500,000	-----	75,430.00	0.413	
Soda ash - Na ₂ CO ₃	500,000	-----	55,160.00	0.302	
Caustic soda - NaOH.....	500,000	-----	97,900.00	0.536	
Operation Yellowboy					
Type I mine water.....	4,150,000	9,850.00	10,236.00	0.007	Little Scrubgrass - low iron - sulfate water. Best treated by stream neutral.
Type II mine water.....	180,000	229,900.00	47,400.00	0.721	Young and Son - medium sulfate - iron water. Operating staff on day shift - plant operates 24 hours per day.
Type III mine water.....	240,000	347,200.00	95,250.00	1.090	Marianna - typical acid mine water, low pH, high iron, sulfate, and solids content. Operating staff on day shift. Plant operates 24 hours per day.
Ozone oxidation.....	72,000	35,575.00	1,840.00	0.070	Capital investment - major items of equipment. Operating cost on kWh used. In research stage. On large scale, the costs would be prohibitive.
Flash distillation.....	1,000,000 5,000,000	2,152,000.00 7,530,034.00	412,450.00 1,668,000.00	1.13 0.9536	DSW Report No. 199 Westinghouse Report to Commonwealth of Penna. using the 0.8 factor for plant scaling, cost identical.
Reverse osmosis.....	1,000,000	1,407,000.00	397,850.00	1.09	O.S.W. Report No. 199 for acid mine water.
Plate and frame design.....	1,000,000	1,440,000.00	105,120.00	0.288	Aerojet General estimate for treating brackish water. Similar to acid mine drainage in solids content.
Spiral wound design.....	1,000,000	≈800,000.00	≈220,000.00	≈0.600	General Dynamics O.S.W. Report 236 - Type A membrane - estimate for treating acid mine water.
Ion exchange					
Acid mine water.....	1,000,000	320,000.00	182,000.00	0.50	Fully automated plant - daily inspection only. Operating cost based on chemicals only.
Brackish water.....	1,000,000	220,000.00	70,000.00	0.19	Operating cost based on chemicals and resin only. Water with 1,000 ppm of anionic and cationic metals.
Subsurface disposal via deep well injection.....	600,000	25,000,000 to 1,500,000.00	43,800.00 to 165,000.00	0.20 to 0.75	No surface treatment facilities required. Surface equipment required, (storage, clarification, filters, pumps, etc...) General data on various types of industrial waste disposal - chemical and steel plants injection pressures variable and depend on well depth (1,850 ft. to 5,440 ft.), strata formation and physical properties of waste.
Impoundment basins and lagoons.....	2,500,000 to 5,000,000	≈125,000.00 *	13,000,000 to 35,000.00	0.18 to 0.60 (0.18 + 0.04 x H)	Acid mine water pumped at a rate of up to 200,000 gallons per day. Average 4,000 gpm for 1 to 4 hour periods during day. ≈50 acre pond-aerations and lime neutralization facilities included.

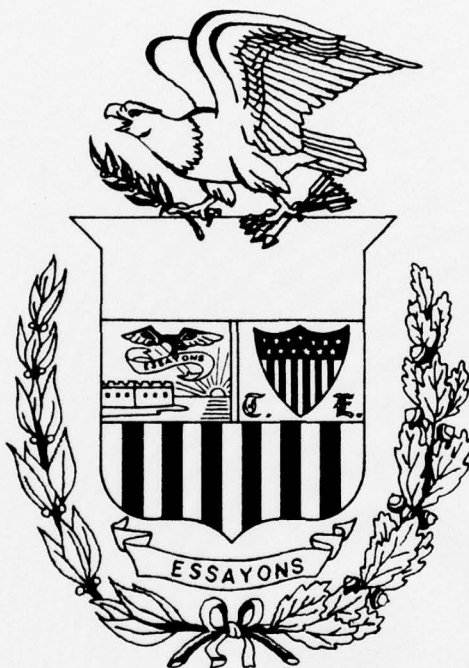
^{1/} Figures in this table should not be compared without reference to variation in cost factors as described in the text.

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